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Evaluation of Physical/Chemical Coal Cleaning and Flue Gas Desulfurization

Interagency Energy/Environment R&D Program Report

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16. ABSTRACT

The report gives results of evaluations of physical coal cleaning (PCC), chemical coal cleaning (CCC), and coal cleaning combined with flue gas desulfurization (FGD). It includes process descriptions, cleaning performances, comparative capital investments, and annual revenue requirements when four coals (with sulfur levels of 0.7% to 5.0%) are cleaned by each of seven conceptual coal cleaning processes. In the three commercial-type PCC processes, coal is treated in dense-medium equipment and by froth flotation or concentrating table. The three CCC processes are KVB, TRW Gravichem, and Kennecott. The seventh process combines PCC and CCC. Economics are provided also for three coal cleaning/FGD combinations to meet the pre-1978 1.2 lb SO_2/MBtu NSPS and the 85% SO_2 reduction NSPS proposed in September 1978. All processes are compared on a 2000-MW power generation basis. PCC is cost effective for meeting the 1.2 lb SO_2/MBtu emission level with coals having sulfur levels below about 1.2%. Coal cleaning/FGD is cost effective for SO_2 emissions control in many specific cases. The CCC processes studied are generally higher in both capital investments and annual revenue requirements; the KVB process is the least expensive.

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ABSTRACT

This evaluation of physical and chemical coal cleaning provides process descriptions, cleaning performances, comparative capital investments, and annual revenue requirements when four coals with sulfur levels of 0.7% to 5.0% are cleaned by each of seven conceptual processes. In three commercial-type physical coal cleaning (PCC) processes, coal is treated in dense-medium equipment and by froth flotation or concentrating table. The three chemical coal cleaning (CCC) processes are the KVB, TRW Gravichem, and Kennecott processes. The seventh process has PCC and CCC in combination. Economics are also provided for three coal cleaning and FGD combinations to meet the pre-1978 1.2 lb SO_2/MBtu NSPS and the 85% SO_2 reduction NSPS proposed in September 1978. All cases are sized for a 2000-MW power plant.

PCC is a cost-effective method for meeting the 1.2 lb SO_2/MBtu emission level with coals having sulfur levels below about 1.2%. PCC plus FGD offers a cost-effective approach for SO_2 emission control in many specific cases. The CCC processes studied are generally higher in both capital investments and annual revenue requirements, the KVB process being the least expensive. When additional economic benefits of using cleaned coal are further quantified, coal cleaning could become even more economically attractive.

CONTENTS

- Abstract . . . iv
- Figures . . . vii
- Tables . . . viii
- Abbreviations, Symbols, and Conversion Factors . . . x

- Executive Summary . . . xiii

- Introduction . . . 1
  - Air Quality Control Standards . . . 3
  - Coal Reserves . . . 4

- Premises . . . 9
  - Design Premises . . . 9
    - Coal-Cleaning Plant . . . 9
    - Power Plant and FGD Premises . . . 9
    - Coal Premises . . . 10
  - Economic Premises . . . 13
    - Project Schedule . . . 13
    - Capital Investment . . . 13
    - Annual Revenue Requirements . . . 14

- Physical Coal Cleaning . . . 16
  - Process Selection . . . 16
  - Physical Coal-Cleaning I Process . . . 17
    - Process Description . . . 17
    - Cleaning Performance . . . 21
  - Physical Coal-Cleaning II Process . . . 21
    - Process Description . . . 21
    - Cleaning Performance and Base-Case Costs . . . 26
  - Physical Coal-Cleaning III Process . . . 26
    - Process Description . . . 29
    - Cleaning Performance . . . 31

- Chemical Coal Cleaning . . . 33
  - KVB Chemical Coal-Cleaning Process . . . 33
    - Process Description . . . 33
    - Cleaning Performance and Base-Case Costs . . . 38
  - TRW Gravichem Chemical Coal-Cleaning Process . . . 38
    - Process Description . . . 38
    - Cleaning Performance and Base-Case Costs . . . 44

Kennecott Chemical Coal-Cleaning Process 44
  Process Description 44
  Cleaning Performance and Base-Case Costs 48

Combination Coal Cleaning 50
  PCC I-KVB Combination Process 50
    Process Description 50
    Cleaning Performance and Base-Case Costs 50

Coal Cleaning - FGD Combinations 53
  PCC I-FGD, KVB-FGD, and PCC I-KVB-FGD Processes 53
    Process Description 53
    Cleaning Performance and Costs 58

Results 59
  Coal-Cleaning Performance 59
    Performance Criteria 59
    Cleaning Performance 59
    Coal Cleaning to NSPS 65
  Economics 67
    Coal-Cleaning Processes 67
    Coal Cleaning and FGD Combinations 76
    Site-Specific Variables 83

Economic Benefits and Penalties of Using Cleaned Coal 85
  Transportation Costs 85
  Savings in Payment to Trust Fund 86
  Crushing and Grinding Costs 86
  Boiler Capacity and Furnace Volume 88
  Boiler Performance and Capacity Factor of the Generating Facility . . 88
  Ash-Handling Costs at the Utility 90
  Improved FGD Operation and Reduction in Boiler Downtime 91
  ESP Size and Cost 92
  FGD Systems Capital and Operating Costs 92
  Reduced Derating of Power Output for FGD Operation 93
  Savings in Stack Gas Reheat Costs 94
  Surface Moisture Added to Coal by Cleaning Processes 94

Conclusions and Recommendations 96

References 98

Bibliography 102

Glossary 108

Appendices

  A. Material Balances and Equipment Lists 112
  B. Economic Data 253

FIGURES

Number		Page
S-1	Capital investment for coal-cleaning processes and FGD . . .	xviii
S-2	Annual revenue requirements for coal-cleaning processes and FGD	xix
S-3	Effect of coal sulfur content on capital investment for coal-cleaning processes	xxii
S-4	Effect of coal sulfur content on annual revenue requirements for coal-cleaning processes	xxiii
1	Coal fields of the conterminous United States	5
2	Remaining identified coal resources of the United States - January 1, 1974	6
3	Rosin-Rammler plots of premise coal sizes based on Bureau of Mines, 1946	12
4	Flow diagram for PCC I process	18
5	Flow diagram for PCC II process	23
6	Flow diagram for PCC III process	28
7	Flow diagram for KVB CCC process	34
8	Flow diagram for TRW Gravichem CCC process	40
9	Flow diagram for Kennecott CCC process	46
10	Flow diagram for PCC I-KVB combination coal-cleaning process	51
11	Flow diagram for limestone slurry FGD process	54
12	Sulfur distribution in PCC I-FGD combination	57
13	Dependence of flue gas reheating energy on proportion of flue gas bypassed	57
14	Power plant stack emissions using various cleaned coals without FGD	66
15	Capital investment for coal-cleaning processes and FGD . . .	70
16	Annual revenue requirements for coal-cleaning processes and FGD	71
17	Effect of coal sulfur content on capital investment for coal-cleaning processes	74
18	Effect of coal sulfur content on annual revenue requirements for coal-cleaning processes	75
19	Capital investment to meet 1.2 lb SO_2/MBtu NSPS by coal cleaning and FGD	79
20	Annual revenue requirements to meet the 1.2 lb SO_2/MBtu NSPS by coal cleaning and FGD	80
21	Capital investment to meet 85% reduction NSPS by coal cleaning and FGD	81
22	Annual revenue requirements to meet 85% reduction NSPS by coal cleaning and FGD	82

TABLES (continued)

Number Page

20 Coal-Cleaning Processes - Annual Revenue Requirement Summary 69
21 Coal-Cleaning Processes with FGD Capital Investment Summary 77
22 Coal-Cleaning Processes with FGD Annual Revenue Requirement Summary 78
23 Coal Properties at Two Similar TVA Power Plants 90
24 Limestone Slurry FGD Costs 93

ABBREVIATIONS, SYMBOLS, AND CONVERSION FACTORS

ABBREVIATIONS

CCC	Chemical coal cleaning
DM	Dense medium
ESP	Electrostatic precipitator
FD	Forced draft
FGD	Flue gas desulfurization
G	Billion or giga
ID	Induced draft
k	Thousand or kilo
M	Million or mega
NSPS	New source performance standards
PCC	Physical coal cleaning
SIP	State Implementation Plan

SYMBOLS AND CONVERSION FACTORS

		To convert		
	From	Multiply by	To	
ac-ft	acre-foot	1,234	cubic meter	m^3
Btu	British thermal unit	1,055	joule or Newton-meter	J or N·m
Btu/lb	British thermal unit per pound	2.326	kilojoules per kilogram	kJ/kg
ft^3	cubic foot	0.028	cubic meter	m^3
ft^3/min	cubic foot per minute	0.0004719	cubic meter per second	m^3/s
ft	foot	0.3048	meter	m
ft/min	foot per minute	0.00508	meter per second	m/s
gal	gallon (U.S.)	3.785	liter	ℓ
gal/min	gallon (U.S.) per minute	0.063	liter per second	ℓ/s
hp	horsepower	0.746	kilowatt or kilojoule per second	kW, kJ/s
mi	mile	1.61	kilometer	km
lb	pound	0.454	kilogram	kg
lb/ft^2	pound per square foot	47.88	pascal	Pa
lb/ft^3	pound per cubic foot	16.018	kilogram per cubic meter	kg/m^3
lb/in^2	pound per square inch	6.894	kilopascal	kPa
lb/MBtu	pound per million Btu	429.9	nanograms per joule	ng/J
ton[a]	ton (2,000 lb)	0.907	megagrams	mg
ton/hr	ton per hour	0.252	kilogram per second	kg/s

---

a. All tons, including tons of sulfur, are expressed in short tons (2,000 lb) in this report.

Note: Metric units are those of the SI (Systeme International) metric system.

EVALUATION OF PHYSICAL/CHEMICAL COAL CLEANING AND FLUE GAS DESULFURIZATION

EXECUTIVE SUMMARY

Emission standards for coal-fired power plants established by the U.S. Environmental Protection Agency (EPA) have made it necessary to consider various strategies for control of sulfur and other polluting emissions. Sulfur can be removed before the coal is burned by physical or chemical coal cleaning, gasification, or liquefaction. Sulfur dioxide (SO_2) can be removed during combustion by fluidized-bed combustion or after combustion by flue gas desulfurization (FGD). As emission standards are tightened, combinations of these approaches may be necessary to allow the use of some coals.

The 1.2 lb SO_2/MBtu heat input maximum emission standards used as the basis of this study were in effect when the study was initiated. New and more strict NSPS were anticipated in response to the Clean Air Act Amendments of 1977. These proposed NSPS were published in the Federal Register in September 1978. The proposed NSPS retained the 1.2 lb SO_2/MBtu requirements and, in addition, required 85% reduction of SO_2 in all uncontrolled emissions above 0.2 lb SO_2/MBtu. These 85% reduction standards are also incorporated into the study. In June 1979 the final NSPS were promulgated. These standards also retain the 1.2 lb SO_2/MBtu standard and in addition require 90% reduction of uncontrolled SO_2 emissions above 0.6 lb SO_2/MBtu and 70% reduction below 0.6 lb SO_2/MBtu with no minimum for solid fuels of the type evaluated in this study.

This report evaluates the performance and economics of three generic physical coal-cleaning (PCC) processes, three chemical coal-cleaning (CCC) processes, a PCC plus CCC combination process, and selected coal-cleaning processes in combination with FGD. The processes are:

- PCC I (dense-medium (DM) vessels, DM cyclones, froth flotation)
- PCC II (DM cyclones at low and high gravity, froth flotation)
- PCC III (DM cyclones, concentrating tables)
- KVB (nitrogen dioxide oxidation of sulfur)
- TRW (ferric sulfate oxidation of sulfur)
- Kennecott (oxygen oxidation of sulfur)

- PCC I plus KVB
- PCC I plus partial scrubbing with limestone FGD
- KVB plus partial scrubbing with limestone FGD
- PCC I plus KVB plus partial scrubbing with limestone FGD

These processes and combinations were studied based upon four premise coals with 0.7%, 2.0%, 3.5%, and 5.0% sulfur levels to show the effects of varying sulfur contents. The 2.0%, 3.5%, and 5.0% sulfur coals represent typical bituminous coals while the 0.7% coal represents a western subbituminous coal. The 0.7% coal has a lower heating value and a higher ratio of organic sulfur to pyritic sulfur than the three bituminous coals.

Combustion of cleaned coal has numerous benefits and a few penalties. Except for the effect on FGD capital and operating costs, the cost comparisons in this study do not include those economic benefits for using cleaned coal.

DESIGN AND ECONOMIC PREMISES

A specific set of design and economic premises established for the comparative calculations are presented in the body of this report. The base-case condition for coal-cleaning evaluations assumes supplying coal to a new 2000-MW midwestern power plant with a design heat rate of 9500 Btu per kWh and operating on a schedule equivalent to full capacity for 5500 hours per year. The power plant life is assumed to be 30 years.

PROCESS DESCRIPTIONS

The three PCC processes represent widely used commercial technology; they were selected for study because they offer a relatively high degree of sulfur reduction compared with other PCC methods. The three CCC processes are not commercial processes, but have been developed to bench-scale or limited pilot-plant stages. Additional development could make significant changes in their technical, and thus economic, potential for sulfur reduction. The PCC processes are somewhat limited in their desulfurization application because they remove only pyritic sulfur. Two of the CCC processes remove significant quantities of organic sulfur in addition to pyritic sulfur.

Physical Coal Cleaning

PCC I Process--

Raw coal is crushed to three size fractions, each of which is processed separately. A DM vessel is used for the coarse coal, a DM cyclone for the intermediate-sized coal, and froth flotation for the fine coal.

PCC II Process--

After crushing, the coarse fraction is processed in DM cyclones operated at low specific gravity to produce a small overflow of highly cleaned coal. The bottoms from the low-gravity cyclones are pumped to high-gravity cyclones to produce "middling" (medium-quality coal) and refuse. The fine coal is recovered by froth flotation.

PCC III Process--

In this process, about two-thirds of the crushed coal feed is a coarse fraction treated in DM cyclones. A fine coal fraction, amounting to about one-third of the coal feed, is cleaned on concentrating tables. The remaining very fine coal fraction is thickened and filtered without cleaning and is added to the clean coal product.

Chemical Coal Cleaning

KVB Process--

This process is the result of several years of research in chemical desulfurization of fuels by KVB, Incorporated, a Research-Cottrell Company. According to KVB the process removes 90% to 99% of the pyritic sulfur and up to 40% of the organic sulfur in coal. It consists of selective oxidation of the sulfur compounds in the coal using gaseous NO_2 at a low temperature and at atmospheric pressure.

TRW Gravichem Process--

TRW Defense and Space Systems Group developed the Gravichem coal desulfurization process and claims the process will remove 90% to 99% of the pyritic sulfur but none of the organic sulfur. The process has been demonstrated in an 8-ton-per-day plant at a TRW test site.

The process consists of a sink-float gravity separation, followed by selective oxidation of the pyrite in the sink fraction with ferric sulfate, followed by acetone leaching to recover elemental sulfur.

Kennecott Process--

Kennecott Copper Corporation began development of this process in 1970 and continued work through May 1975 when the process was demonstrated at a bench-scale level. The process consists of an oxidation system in which 85% to 95% of the pyritic sulfur and up to 30% of the organic sulfur in the coal are oxidized to soluble sulfates by sparging oxygen through pulverized coal at a high temperature and pressure.

RESULTS OF PHYSICAL AND CHEMICAL COAL-CLEANING STUDY

Cleaning Performance

The estimated performances of the six coal-cleaning processes described in the premises are shown in Table S-1 for the 5.0% sulfur coal. The PCC processes remove only pyritic sulfur and have a considerably lower sulfur removal efficiency than the CCC processes. In addition, noncoal minerals are removed and some of the coal is lost.

TABLE S-1. CLEANING PERFORMANCE OF PHYSICAL AND CHEMICAL COAL-CLEANING PROCESSES

5% SULFUR COAL

(MOISTURE-FREE BASIS)

		Cleaned coal						
		Physical cleaning			Chemical cleaning			Combination
	Raw coal	PCC I	PCC II	PCC III	KVB	TRW Gravichem	Kennecott	PCC I - KVB
Total sulfur, %	5.00	3.67	3.51	3.78	1.32	1.95	1.81	1.26
Pyritic sulfur, %	3.35	2.02	1.86	2.13	0.07	0.07	0.40	0.04
Organic sulfur, %	1.59	-	-	-	1.21	1.70	1.37	1.18
Sulfate sulfur, %	0.06	-	-	-	0.04	0.04	0.04	0.04
Ash, %	16.7	10.1	9.3	10.6	13.7	13.6	15.8	8.0
Btu/lb	12,000	13,000	13,000	12,900	12,900	12,300	11,300	13,600
Btu recovery, %	-	90.7	91.4	90.7	98.8	98.9	94.1	90.2
Weight recovery, %	-	84.2	84.0	84.7	92.1	92.8	100.1	80.1
Total sulfur, lb/MBtu	4.17	2.84	2.68	2.93	1.02	1.51	1.60	0.93
Sulfur removal, % Btu basis	-	32	36	30	76	64	62	78

The CCC processes remove most of the pyritic sulfur and the KVB and Kennecott processes also remove 30% to 40% of the organic sulfur.

Coal cleaned by the physical processes contains from 30% to 36% less sulfur than the raw coal. Weight and Btu recoveries are about 84% and 91% respectively. There is also an increase in cleaned coal heating value and a reduction in ash. Sulfur removal efficiencies of the CCC processes range from 62% to 76% with no appreciable weight or Btu loss. There is also less increase in heating value and less reduction in ash content compared with coal cleaned in the PCC processes.

Base-Case Economics

Base-case capital investment and annual revenue requirement summaries for the six processes are shown in Table S-2 and in Figures S-1 and S-2. Costs of a limestone scrubbing FGD system with pond disposal of sludge are also included in Table S-2 for comparison with the coal-cleaning processes. All cost data are based on processes serving a 2000-MW power plant and raw coal containing 5% sulfur, as described in the premises.

TABLE S-2. BASE-CASE PHYSICAL AND CHEMICAL COAL CLEANING

ECONOMIC DATA SUMMARY

Process	% sulfur reduction	Capital investment $/kW	Capital investment ¢/lb sulfur removed/yr	Annual revenue requirements Mills/kWh	Annual revenue requirements ¢/lb sulfur removed
PCC I	32	34	37	2.7	16
PCC II	36	40	40	2.9	16
PCC III	30	39	45	2.9	18
KVB	76	86	52	8.3	27
TRW	64	114	78	7.3	28
Kennecott	62	141	94	14.7	54
PCC I-KVB	78	115	59	11.0	32
FGD	85	119	68	5.6	18

Basis
2,000 MW, 5.0% sulfur in coal, 5,500 hr/yr, 9,500 Btu/kWh heat rate. FGD is limestone scrubbing, 25% scrubber redundancy, with pond sludge disposal. Percent sulfur reduction based on raw and cleaned coal heating values.

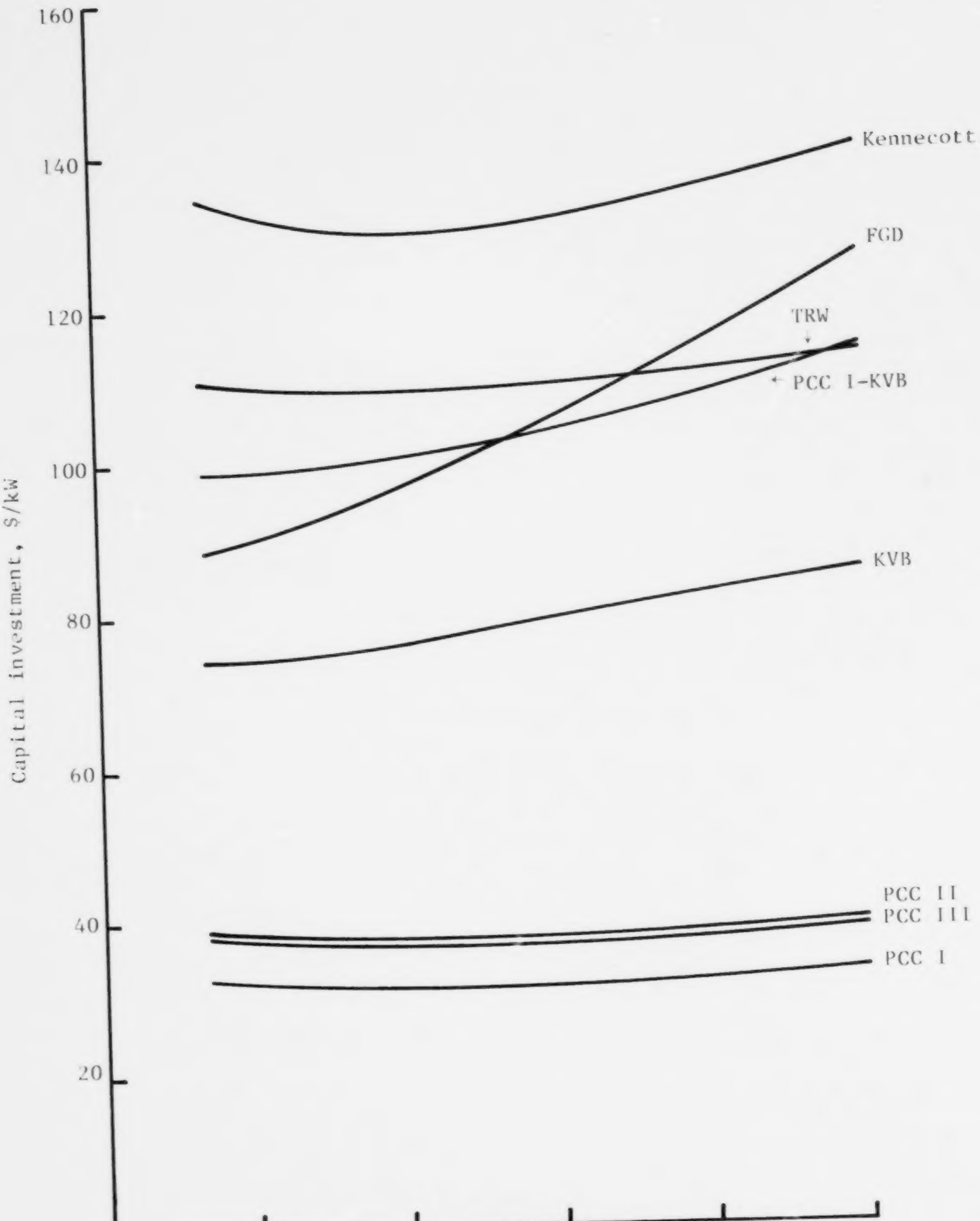


Figure S-1. Capital investment for coal-cleaning processes and FGD.

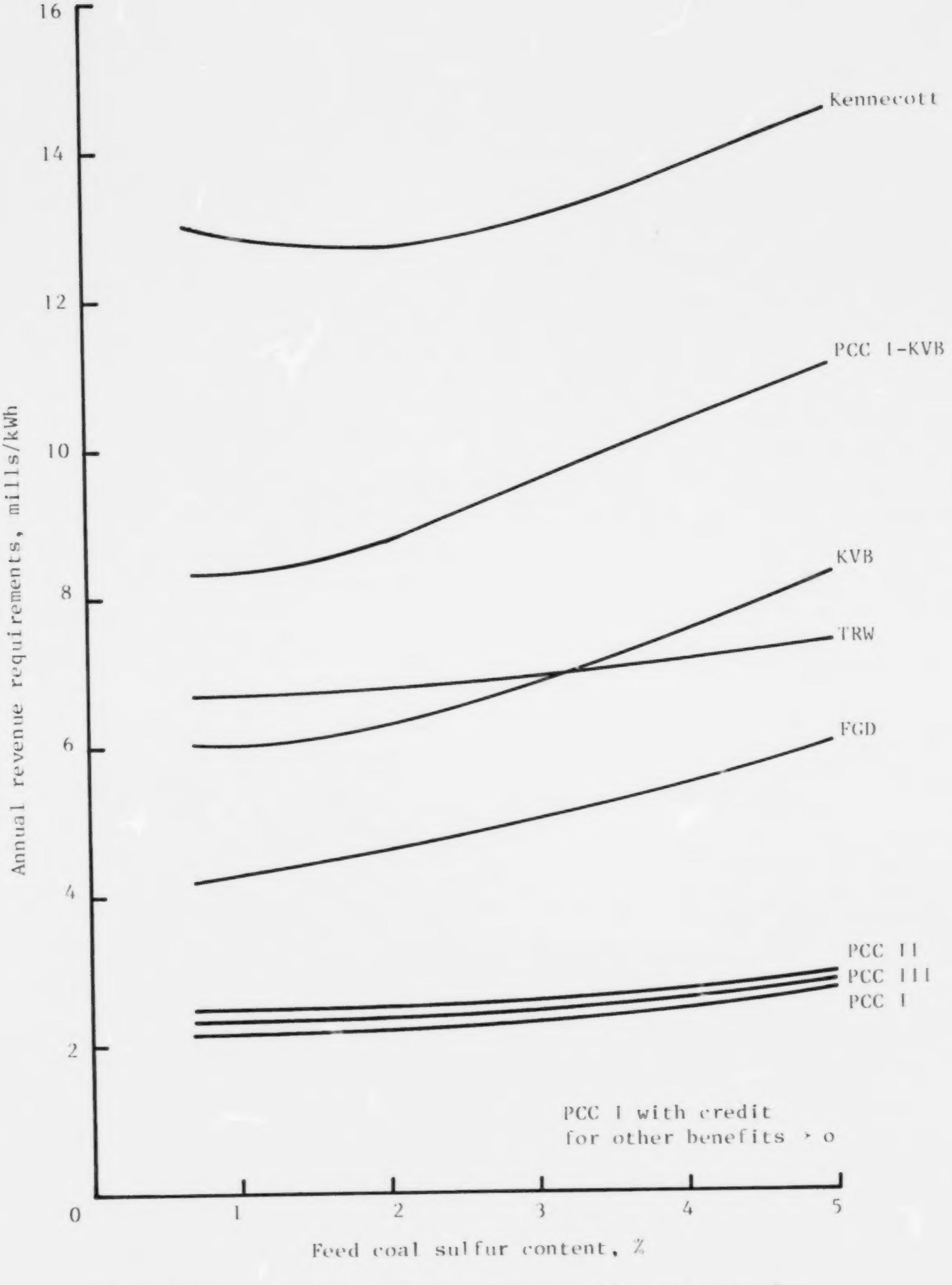


Figure S-2. Annual revenue requirements for coal-cleaning processes and FGD.

The three PCC processes have capital investments of 34 to 40 \$/kW and annual revenue requirements of 2.7 to 2.9 mills/kWh; the capital investments are equivalent to 37 to 45 ¢/lb sulfur removed per year and the annual revenue requirements are 16 to 18 ¢/lb sulfur removed. The major cost differences in direct investment are in lower coal-cleaning equipment costs for the PCC I process, higher coal storage costs for the PCC II process, and slightly higher coal-sizing costs for the PCC III process. Refuse disposal and land costs for the three processes do not differ greatly.

Annual revenue requirements for each of the PCC processes are about the same. Large direct costs such as coal loss, labor, and maintenance are similar for all three processes. Higher utility costs, particularly electricity, account for slightly higher total direct costs for the PCC II process. Lower capital charges account for most of the lower annual revenue requirements of the PCC I process. When cost is related to sulfur removal efficiencies, the position of the PCC II process is improved while the PCC III process becomes the most expensive process.

Capital investments and annual revenue requirements for the three CCC processes all are larger than for the PCC processes and also differ more widely in cost among themselves. Capital investments for the CCC processes range from 86 to 141 \$/kW and annual revenue requirements range from 7.3 to 14.7 mills/kWh. Capital investments range from 52 to 94 ¢/lb sulfur removed per year and annual revenue requirements range from 27 to 54 ¢/lb sulfur removed. The KVB process has the lowest capital investment and the KVB and TRW processes have the lowest annual revenue requirements.

There are large differences in equipment costs for the CCC processes. The reactor, regenerator, acetone leaching, and acetone recovery systems are high-cost elements in the TRW process. The reactor area, filtration, and agglomerization equipment are high-cost elements in the Kennecott process. The KVB process operates at atmospheric pressure and at low temperature, and consequently has the lowest capital investment. Because the KVB process is capable of high sulfur removal efficiency, it is only slightly higher than the PCC processes in capital investment per unit of sulfur removed.

All of the CCC processes have much higher annual revenue requirements than the PCC processes, primarily because of large conversion costs, indirect costs related to capital investment, and, in the KVB and Kennecott processes, large raw material costs. The relatively low annual revenue requirements of the TRW process are largely a result of low raw material costs. Although it has the lowest conversion costs, the KVB process has the highest raw material costs--more than half for sodium hydroxide. (A recent communication from KVB stated that further development work has been completed and that a substantial reduction in sodium hydroxide usage has been realized. This improvement in sodium hydroxide usage is not reflected in the economics presented in this report.) With the Kennecott process, high raw material costs and high conversion costs, particularly for steam and electricity, combine to produce the highest annual revenue requirements of the processes evaluated. The differences in revenue requirement between the KVB process and the TRW process are reduced when costs are related to amount of sulfur removed. In all cases, however, the CCC processes remain more expensive to operate than the PCC processes.

For comparison, costs for limestone scrubbing FGD units with 85% sulfur reduction for a 2000-MW utility are included in Table S-2. The capital investment ($/kW) for the FGD unit is much higher than those for the PCC processes and higher than the capital investment of the KVB process. Annual revenue requirements (mills/kWh) for the FGD system are higher than those of the PCC processes although lower than those of the CCC processes.

Since the processes remove different percentages of sulfur from the raw coal, capital and operating costs per kilowatthour are not directly comparable. When compared on the basis of cost per unit of sulfur removed, the capital investment and revenue requirements of the FGD system are greatly reduced relative to the coal-cleaning processes. Figure S-3 shows the effect of coal sulfur content on the capital investments of the six coal-cleaning processes and FGD. Annual revenue requirements are shown in Figure S-4. The cost comparisons are shown on the basis of quantity of sulfur removed. On this basis the KVB process with its high removal efficiency and relatively low capital investment compares favorably with the FGD system in capital investment. The PCC processes also remain less costly in capital investment than the FGD system in terms of cost versus sulfur removed. On the same basis the annual revenue requirements of the FGD system are more than those of the PCC processes but remain lower than all the CCC processes. The annual revenue requirements shown in Figure S-4 do not include credit for the other benefits of using cleaned coal.

Economics of Coal Cleaning Plus FGD

When the PCC I process is combined with partial FGD scrubbing as an SO_2 emission control method to meet 1.2 lb SO_2/MBtu emission limits that were in effect when this report was prepared, the capital investment ($/kW) is less than for FGD alone. The annual revenue requirements (mills/kWh) are generally the same as for FGD alone. PCC I plus FGD has lower annual revenue requirements at sulfur contents of raw coal below about 3%. When other benefits of using cleaned coal such as reductions in ash costs, coal transportation costs, maintenance costs, peaking capacity, rated capacity, and plant availability are credited, PCC plus FGD should also be competitive at the higher sulfur levels.

The capital investment for PCC I plus FGD to meet the 85% SO_2 removal proposed in the September 19, 1978, Federal Register is approximately the same as for FGD alone. The annual revenue requirements for PCC I plus FGD for the 85% SO_2 removal are slightly higher than for FGD alone, although this difference can be eliminated when other economic benefits of using clean coal are credited.

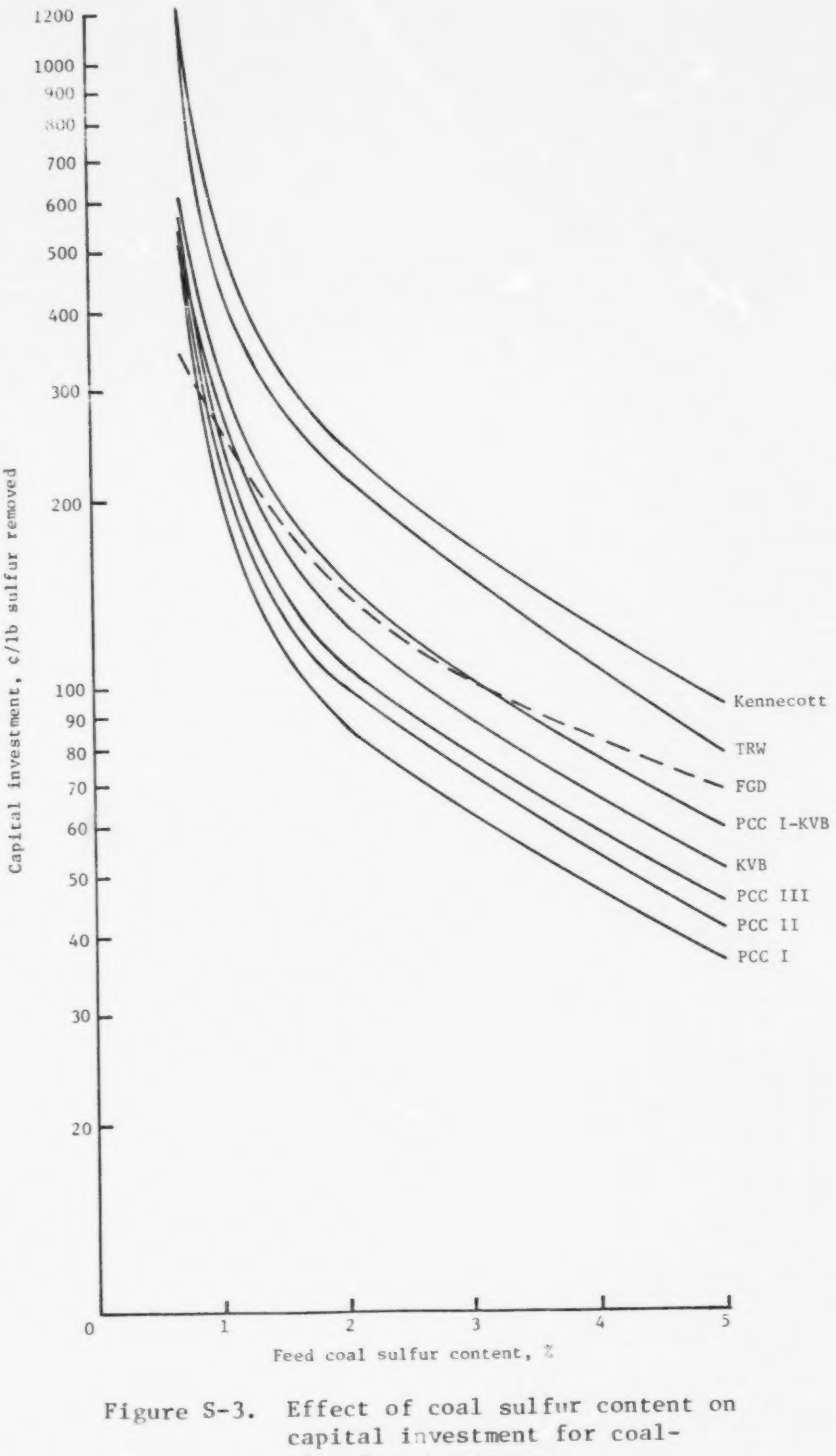


Figure S-3. Effect of coal sulfur content on capital investment for coal-cleaning processes.

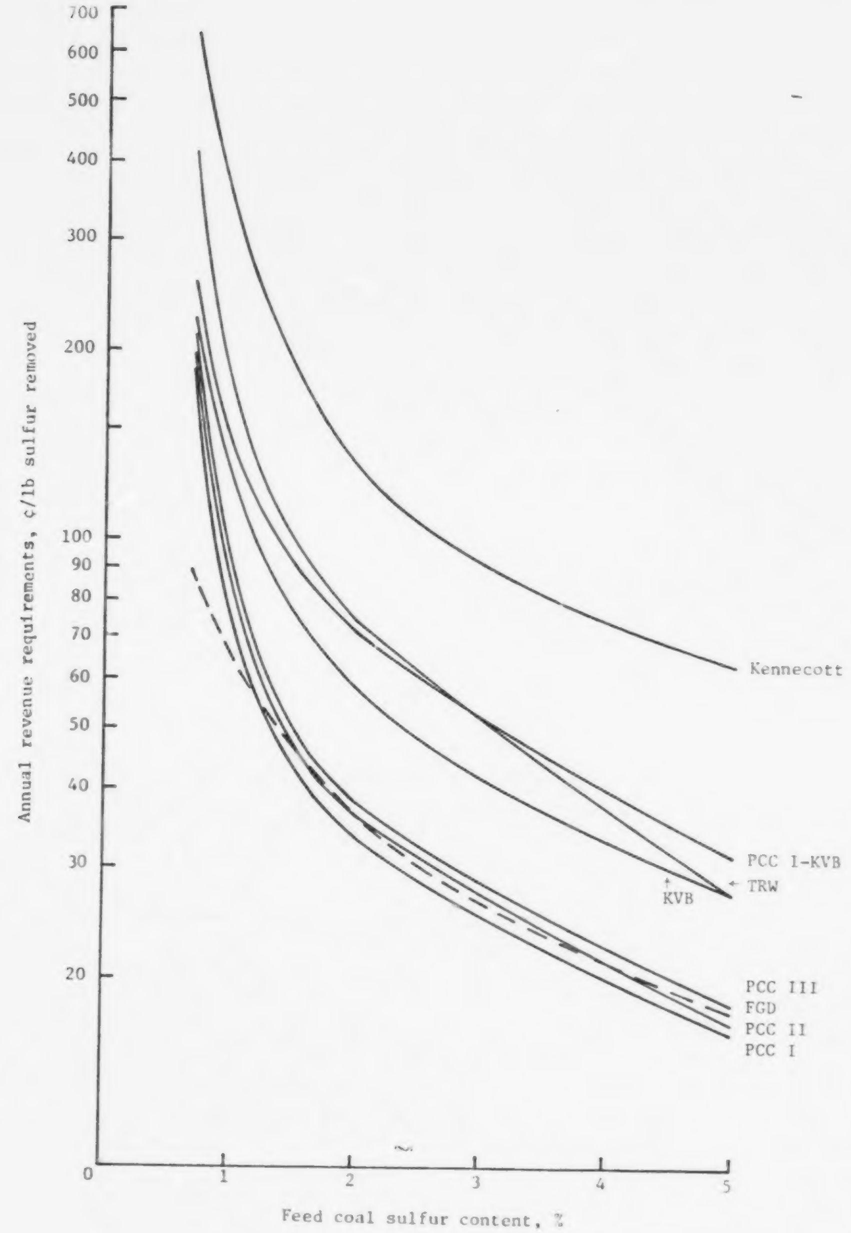


Figure S-4. Fffect of coal sulfur content on annual revenue requirements for coal-cleaning processes.

When coal cleaned by the KVB process is used with partial FGD scrubbing to meet 1.2 lb SO_2/MBtu emission levels, the capital investment ($/kW) is approximately the same as FGD alone for equal sulfur levels in the raw coal. For sulfur levels in the raw coal below about 3%, the KVB process alone will meet 1.2 lb SO_2/MBtu emission levels without FGD. To meet the 85% SO_2 removal, the KVB process plus partial FGD scrubbing has a capital investment ($/kW) approximately the same as that of FGD alone for raw coal sulfur levels above about 3%. For lower sulfur levels, the KVB process plus FGD has a higher capital investment. With either standard, the capital investment required for the PCC I plus KVB plus FGD case is higher than for PCC I plus FGD, KVB plus FGD, or FGD alone.

The annual revenue requirements (mills/kWh) to meet 1.2 lb SO_2/MBtu emission levels with PCC I plus FGD are higher than for FGD alone for raw coal sulfur levels above about 3%. Below about 3% raw coal sulfur levels, the annual revenue requirements for PCC I plus FGD are lower than for FGD alone. The annual revenue requirements for KVB plus FGD and for PCC I plus KVB plus FGD are higher than for FGD alone at all raw coal sulfur levels.

The annual revenue requirements (mills/kWh) to meet 85% SO_2 removal are higher for PCC I plus FGD, KVB plus FGD, or PCC I plus KVB plus FGD than for FGD alone.

Site-Specific Cost Factors

It should be emphasized that many site-specific variables affect the economics involved in determining the lowest cost method to meet emission standards. Some of these are discussed below.

Emission Standards--

Costs for coal cleaning, alone or in combination with FGD, will be most attractive for plants under higher SIP standards, less attractive for 1.2 lb SO_2/MBtu emission limits, and least attractive for 85% SO_2 removal, as compared with FGD alone. Raising the proposed 0.2 lb SO_2/MBtu floor in the 85% SO_2 removal NSPS would have increased the number of situations in which coal cleaning would be economically attractive for that standard.

Coal Properties--

Higher ratios of pyritic sulfur to organic sulfur will result in improved costs for most situations utilizing coal cleaning. Larger pyrite crystal size or more favorable particle distribution will make the pyrite easier to remove by PCC and will also result in improved costs. Data exist which show that coal cleaning will not only reduce the sulfur level, but also the sulfur variability in coal. Coal cleaning plus FGD will generally have more attractive costs for a raw coal with high sulfur variability. The size and cost of a coal-cleaning plant to deliver a specified heat load are also obviously dependent on the heat content of the raw coal.

Plant Location--

Plant location influences costs in a variety of ways. These include construction and operating labor rates; need for weather protection; requirements for barge, truck, or rail unloading facilities; size of raw and cleaned coal storage facilities; and rates for utilities. For example, the PCC and CCC plants evaluated in this study include a 15-day supply of cleaned coal (power plant usage basis) plus facilities for stacking, storage, and reclaim. In addition, there are similar facilities for a 15-day supply of raw coal. If the coal-cleaning plant is located adjacent to the power plant, the cleaned coal could be considered as part of the power plant normal 90- to 120-day stockpile. This would reduce both the installed capital and working capital.

Process Commercial Development--

The PCC processes studied are in a commercial stage of development whereas the CCC processes are all relatively undeveloped. Future development work on the CCC processes could substantially increase or decrease the projected costs. The significant reduction in sodium hydroxide usage recently reported by KVB for their process would make it more economically attractive.

While the use of absorbents such as limestone to remove SO_2 during combustion has not been fully successful in the past, recent work reported by Battelle burning pellets made of finely ground limestone and coal showed a sulfur capture of about 75% in the boiler. After cleaning, the cleaned coal has a fine particle size and in some cases it must be pelletized for shipping or storage. These grinding and pelletizing or briquetting costs are included in the costs of the CCC processes. Grinding limestone and pelletizing it with the cleaned coal, using cement as a binder, would offer many process and cost advantages for both SO_2 control methods. For many coals this technique, if perfected, used with coals cleaned by the KVB process could even meet 85% SO_2 removal standards.

Other Economic Benefits and Penalties of Using Cleaned Coal

In evaluating the capital investment and annual revenue requirements associated with coal cleaning, it is useful to also assess the other economic benefits and penalties that result from use of cleaned coal. In addition to the primary benefit that the cleaned coal is lower in sulfur, it is generally also lower in ash and higher in heating value, although often higher in surface moisture. Combustion of coal with these characteristics has numerous benefits as well as certain disadvantages to the user. The net effect is a credit which may be of sufficient magnitude to offset some of the increased cost of cleaned coal.

Except for the effect on FGD capital and operating costs, the cost comparisons in this study do not include these economic benefits for using cleaned coal. Recent studies have shown penalties of up to $8 per ton for coals with combined ash and sulfur contents up to 25%. This represents a potential net cost advantage of up to about 3 mills/kWh for using clean coal. These studies show a 2 mills/kWh net cost advantage for the 5% sulfur coal used in this study with lower amounts for the coals with lower sulfur levels. Additional work is needed to quantify the economic magnitude of these economic benefits and penalties. Several of the significant economic effects of using cleaned coal are discussed below.

Transportation Costs--

Coal beneficiation at the mine decreases the cost of coal transportation by increasing the heating value of the coal, consequently reducing the quantity of coal necessary to supply a given heat requirement.

Pension and Benefit Trust Fund--

Provisions of the 1978 UMW contract require payment by the mine operator of $1.385 to the UMW Pension and Benefit Trust Fund for each ton of coal shipped to a consumer. Less cleaned coal is needed to supply a specified heat load requirement and, if the coal-cleaning plant is at the mine, the reduced tonnage will decrease this payment.

Pulverization Costs--

PCC, by reducing mineral matter, decreases coal hardness and facilitates crushing. The increased heating value of cleaned coal also reduces the quantity of coal to be crushed. The size of the cleaned coal product is considerably smaller than that of raw coal so that significant pulverization costs, which are already covered in the coal-cleaning costs, are saved. Additional surface moisture of cleaned coal may partially offset these advantages.

Boiler Capacity--

The higher heating value of cleaned coal decreases the possibility that the utility boiler capacity will be derated because of deteriorating coal quality. Also, by reducing the slagging tendency of the coal, coal cleaning can permit the design of furnaces with higher heat transfer rates and correspondingly smaller furnace volume.

Boiler Performance--

Cleaned coal can improve boiler performance by reducing slagging, fouling, and corrosion problems. This can significantly reduce the cost of boiler operation and maintenance and increase the availability of the generating facility.

Ash Handling--

Ash handling and disposal costs are decreased since coal cleaning generally reduces the total amount of ash handled. Less sensible heat is lost in the bottom ash because of the lower ash levels.

FGD Operation--

FGD systems generally have markedly better operation with low-sulfur coals. When coal cleaning is followed by FGD scrubbing, the lower sulfur level of the cleaned coal should give less FGD system downtime and a better overall utility availability. Better overall utility availability is also obtained with cleaned coal because of the more consistent SO_2 inlet concentration to the FGD system.

FGD Capital and Operating Costs--

Investment and operating costs of FGD systems are proportional to inlet sulfur concentration. Boilers burning high-sulfur coal have higher capital costs because of the necessity for a large absorbent preparation facility, scrubber system, and area for waste disposal. Corresponding savings in operating costs should also be realized with the low-sulfur cleaned coal, particularly if partial scrubbing can replace full scrubbing. These cost advantages for coal cleaning plus FGD have been taken into account in this study.

ESP Size and Cost--

The resistivity of fly ash is a major factor in determining the collection area of the ESP. Resistivity is determined by many factors, including ash composition and concentration and SO_3 level in the gas. With conventional ESP units the removal of fly ash will generally be more difficult with the low sulfur levels of cleaned coal. ESP costs may be increased although ash levels may be partly compensating. Other systems such as hot side ESP, bag filters, or pulsed ESP may be less expensive in certain cases when burning cleaned coal.

Surface Moisture--

Higher moisture levels in cleaned coal resulting from the smaller particle sizes increase transportation costs and result in a minor heat loss when the water is heated and vaporized during the combustion process.

Energy Requirements

Energy estimates for the six processes are shown in Table S-3. The comparison is made on the basis of total energy input consisting of raw coal feed and utilities. In addition to the electrical, steam, diesel fuel, or natural gas energy consumed in the process, there are other energy losses and usages that are specific for each process. Additional energy is needed to vaporize the extra surface moisture of cleaned coal and to heat the water vapor to stack temperature. The three PCC processes have a significant Btu loss because part of the coal is discharged in the refuse stream.

The Kennecott process also has a small coal usage because a portion of the coal chemical structure is altered during the cleaning process. This energy aids in holding the reaction temperature at the desired level, thereby replacing an equivalent amount of energy in the form of steam. In addition, the coal product from the Kennecott process has an oxygen uptake resulting in an additional Btu loss.

The KVB process utilizes a reaction at atmospheric pressure and at relatively low temperatures. As a result, the 6.5% total energy usage for the KVB process is significantly lower than that of the other processes.

TABLE S-3. PHYSICAL AND CHEMICAL COAL-CLEANING

ENERGY USAGE AND LOSSES

	PCC I	PCC II	PCC III	KVB	TRW	Kennecott
Total energy input, 10^{12} Btu/yr	115.6	115.2	115.3	111.8	115.4	125.7
Energy Lost or Used						
Sulfur removed	0.7	0.7	0.6	1.2	1.0	1.0
Coal lost or used, % of input	8.6	8.0	8.6	0	0	1.3
Moisture increase in product coal	0.2	0.5	0.1	0.3	1.8	0.8
Oxygen uptake in coal	-	-	-	-	-	2.9
Utilities						
Electricity, % of input	0.04	0.08	0.04	0.6	0.5	1.7
Steam, % of input	0	0	0	4.4	6.1	9.2
Natural gas, % of input	0	0	0	0.02	0	0
Diesel fuel, % of input	0.02	0.02	0.02	0	0	0
Total	9.6	9.3	9.4	6.5	9.4	16.9

Basis

2,000-MW utility power plant equivalent, 5,500 hr/yr operation, 9,500 Btu/kWh design heat rate, 5% sulfur coal.

CONCLUSIONS AND RECOMMENDATIONS

1. PCC is a commercial, cost-effective method for meeting 1.2 lb SO_2/MBtu emission levels for raw coals with sulfur levels below about 1.2%. Older utility plants that are required to meet less stringent SIP's or industrial boilers could use coals with even higher sulfur levels.

2. PCC plus partial scrubbing with limestone FGD is generally cost effective in meeting 1.2 lb SO_2/MBtu emission levels, as compared with FGD alone, for raw coals with sulfur contents below about 3%. Above this sulfur level, the PCC plus FGD method generally has lower capital investment but slightly higher annual revenue requirements. When other benefits of using cleaned coal are credited, PCC plus FGD should also be competitive at the higher sulfur levels.

3. Coal cleaning plus partial scrubbing with limestone FGD is generally less cost effective in meeting 85% SO_2 removal than limestone FGD alone. KVB plus FGD and PCC I plus FGD have about the same capital investment as FGD for raw coal sulfur levels above about 3% but have higher annual revenue requirements. Again, when the other benefits of using clean coal are credited, PCC plus FGD should also be competitive at the higher sulfur levels.

4. The CCC processes are generally higher in both capital investments and annual revenue requirements than the PCC processes. The Kennecott process is most expensive and the KVB process the least expensive of the CCC processes studied.

5. The KVB process or KVB plus partial FGD scrubbing generally have lower capital investments and higher annual revenue requirements (mills/kWh) than FGD alone. Recent work by KVB to decrease the sodium hydroxide usage of this process could make a significant improvement in annual revenue requirements. All CCC processes require additional process development before costs can be more accurately calculated.

6. The KVB process is the most energy efficient process of the PCC and CCC processes studied.

7. The use of cleaned coal has many additional economic benefits and a few penalties. The net result could be a cost reduction which would substantially reduce the costs of coal cleaning. Further work should be done to quantify these factors.

8. A potentially advantageous SO_2 emission control approach that should be investigated further is pelletization of the already finely ground clean coal with limestone for further sulfur removal during combustion. This could expand the potential for economic sulfur removal by coal cleaning.

EVALUATION OF PHYSICAL/CHEMICAL COAL CLEANING
AND FLUE GAS DESULFURIZATION

INTRODUCTION

Substantial increases in coal use are projected for the United States in the coming decades. Utility consumption is expected to nearly double from 404 million tons in 1975 to 779 million tons in 1985 and almost triple to a billion tons by 2000 according to governmental expectations (Executive Office of the President, 1977). This increase in coal usage will substantially increase sulfur dioxide (SO_2) air pollution emissions unless positive steps are taken to either: (1) remove the sulfur before the coal is burned by physical or chemical coal cleaning, gasification, or liquefaction; (2) remove the SO_2 as the coal is burned by fluidized-bed combustion processes; or (3) remove the SO_2 from stack gases after combustion by using flue gas desulfurization (FGD).

This report deals with the performance and economics of physical coal-cleaning (PCC) and chemical coal-cleaning (CCC) processes when used for the control of SO_2 emissions from conventional coal-fired power plants. For purposes of comparison, three PCC and three CCC processes are assessed separately, in a PCC-CCC process combination, and in combination with FGD. Four premise coals are used to show the effects of varying sulfur contents and of varying responses to the cleaning processes because of different ratios of pyritic to organic sulfur.

The methods of sulfur removal differ widely in maturity of commercial development, in cost, and in operational performance. In addition to size control for market requirements, some degree of PCC for the removal of pyritic sulfur and ash materials has been practiced in the United States since 1890 (Agarwal et al., 1975). For these early operations, belt washers, bumping tables, and other precursors to the modern concentrating table were adapted from ore beneficiation practices to coal cleaning. The Baum coal-washing machine for alternately flooding and draining a moving bed of coal was in commercial operation in Europe well before 1900 (Baum, 1894) and was introduced into the United States in 1928 (Coal Preparation, 1968). Basically, all methods used gravity separation, taking advantage of the fact that "pure" coal has a lower specific gravity than the pyrite or the ash materials.

During the last quarter century, a succession of equipment innovations and improvements has brought a new sophistication to coal cleaning. But except for froth flotation the leading commercial methods still are based on gravity separation under static or dynamic conditions. One of the most thorough commercially practical processes for separation of coal and refuse material is gravity separation in a dense-medium magnetite and water slurry controlled at a precise specific gravity within the range of 1.34 to about 1.6. This method is used in this study for coal fractions of coarse or intermediate particle size, but froth flotation or tabling is used for the fine coal fractions.

Over the years, most U.S. coal cleaning has been oriented to metallurgical coal and to its export requirements rather than to steam coal for use by utilities. Increased mechanization and increased use of continuous mining equipment, however, have resulted in raw coal that contains more impurities. As a result, many utilities have been offered coal of increased ash content and lower calorific value and the need for coal cleaning has increased.

Published data on tonnages of coal cleaned are not well divided by coal use but in the period 1965-1975 an estimated 60% of all coal produced in the United States received some beneficiation--often of very limited extent (Gibbs and Hill, 1978). On the same basis, 20% to 30% of the raw coal destined for utilities received at least partial beneficiation. This low percentage means that coal cleaning has been considered economical for utility use only under poorer than average conditions of coal quality and transportation distance or unusual conditions of use. Now, however, the air quality control standards sharply limit the SO_2 emissions from power plants and coal cleaning is beginning to be used as an SO_2 control measure.

Because of the increasingly stringent requirements for sulfur removal at power plants, interest has increased in all technologies for sulfur control. These requirements have increased the cost of sulfur control in general and have opened the door for consideration of approaches that are not commercially proven technically or economically.

In contrast to the extensive commercial history of PCC, the CCC processes are relatively undeveloped. Most CCC processes have not been developed past bench scale, but the TRW Gravichem process has been demonstrated in an 8-ton-per-day pilot plant. None have been used commercially.

A number of approaches to CCC have been investigated. Some of these are:

- Nitrogen oxides oxidation (KVB)
- Ferric sulfate oxidation (TRW)
- Oxygen oxidation (Kennecott)
- Air oxidation (Department of Energy)
- Chlorine oxidation (Jet Propulsion Laboratory)

- Hydrothermal (Battelle)
- Alkaline oxidation (Iowa State)
- Microwave (General Electric)
- Bacterial (Jet Propulsion Laboratory, Ohio State, and others)

In addition, other processes use pretreatment followed by physical separation. Examples are chemical comminution followed by a physical sink-float separation (Otisca) or a chemical pretreatment with iron carbonyl followed by magnetic separation (Magnex). CCC is an emerging technology and considerably more development effort is needed before costs, problems, and degree of sulfur removal are known with accuracy.

FGD now has a history in regular power plant application since 1973. FGD processes continue to be improved in operating reliability, in SO_2 removal efficiency, and in sludge disposal methods (Kennedy and Tomlinson, 1978). Processes for recovery of the SO_2 byproduct are at a much earlier stage of commercialization.

AIR QUALITY CONTROL STANDARDS

Following the Clean Air Act of 1970, the U.S. Environmental Protection Agency (EPA) issued Federal Standards for New Stationary Sources, often called new-source performance standards or NSPS (Chaput, 1976). The maximum emission level for SO_2 was established as 1.2 lb SO_2/MBtu heat input to boilers in power plants built after August 17, 1971. Also, each state prepared an EPA-approved State Implementation Plan (SIP) for power plants (Crenshaw et al., 1976). These emission levels depended on the atmospheric sensitivity at the plant location and range from 1.2 to about 0.3 lb SO_2/MBtu. Some states have required FGD regardless of the SO_2 emission level. A number of SIP standards for power plants built prior to August 17, 1971, have been more liberal than the 1.2 lb SO_2/MBtu maximum for new plants but they are too diverse and changeable for generalization and have to be obtained currently on a plant-by-plant basis.

Based on the Clean Air Act Amendments of 1977, EPA proposed more restrictive emission standards for power plants whose construction commenced after September 18, 1978 (Federal Register, 1978). The proposed standards include a general requirement of 85% removal of the SO_2 equivalent in the raw coal, down to an emission level of 0.2 lb SO_2/MBtu to the boiler. This degree of removal may be shared among sulfur removal processes such as coal cleaning, bottom and fly ash removal, and FGD. Both the 1.2 lb SO_2/MBtu NSPS and the proposed 85% removal NSPS are used in this study. In June 1979, the final NSPS were promulgated. These standards also retain the 1.2 lb SO_2/MBtu standard and in addition require 90% reduction of uncontrolled SO_2 emissions above 0.6 lb SO_2/MBtu and 70% reduction below 0.6 lb SO_2/MBtu with no minimum for solid fuels of the type evaluated in this study.

Desulfurization therefore serves a diverse set of emission limits, depending on whether the power plant was new or existing on August 17, 1971, or on September 18, 1978, and depending on existing and impending SIP requirements. The needed desulfurization will continue to be specific to the coal and to the current limit for the power plant location.

COAL RESERVES

As shown in Figure 1, coal deposits are widely distributed across the United States, but most bituminous coal is found in the eastern half of the country and virtually all subbituminous coal and lignite occur in the Western States. The tonnage and its heating value for each rank of coal deposit are charted by state in Figure 2. The two scales are arranged to provide the same bar length for tonnage and for heating value for bituminous coal. Lignite deposits are most extensive in North Dakota and Montana, but Texas and South Dakota also have useful amounts. The largest subbituminous coal deposits are in Montana, Wyoming, and Alaska, with New Mexico and Colorado having smaller but very significant tonnages. Bituminous coal is the most widely distributed among states. Anthracite coal is virtually restricted to Pennsylvania. For the country as a whole, both tonnge and heating value of coal ranks occur in the decreasing order of bituminous, subbituminous, lignite, and anthracite. All coals receive some degree of preparation for their markets but cleaning of steam coal for utility use has been confined to the bituminous type.

Since the 1940's electric utilities have gained an increasing share of U.S. coal consumption. In 1973 this share reached 70% (Averitt, 1975). Much of the percentage increase was the result of declining use by other consumers. The major part of coal production has been bituminous coal from Pennsylvania, West Virginia, Illinois, Kentucky, and Ohio, but in recent years the production of western coal has gained impressively. In fiscal 1975 the subbituminous and bituminous western coals supplied 17% of all U.S. utility coal and they comprised 55% of U.S. utilities coal of under 1% sulfur (Hunter, 1976).

The gains by western coals have been due partly to a general growth in power plant capacity in the West and partly to increased use of western coal farther east. Because of its characteristically low sulfur content of less than 1%, subbituminous coal from Montana and Wyoming has been used in some existing Central States power plants to meet emission standards without FGD. Under the proposed emission standards of 1978, virtually no new power plants and fewer existing units would have this sulfur-control option. This limitation can be expected to restrict the use of subbituminous coal in the Central States.

Knowledge of the cleanability of coal reserves is of obvious importance and much effort has been put to estimating their sulfur reduction potential using gravity-type separations. The results show the potential of PCC for meeting emission standards and they provide a useful background for this study.

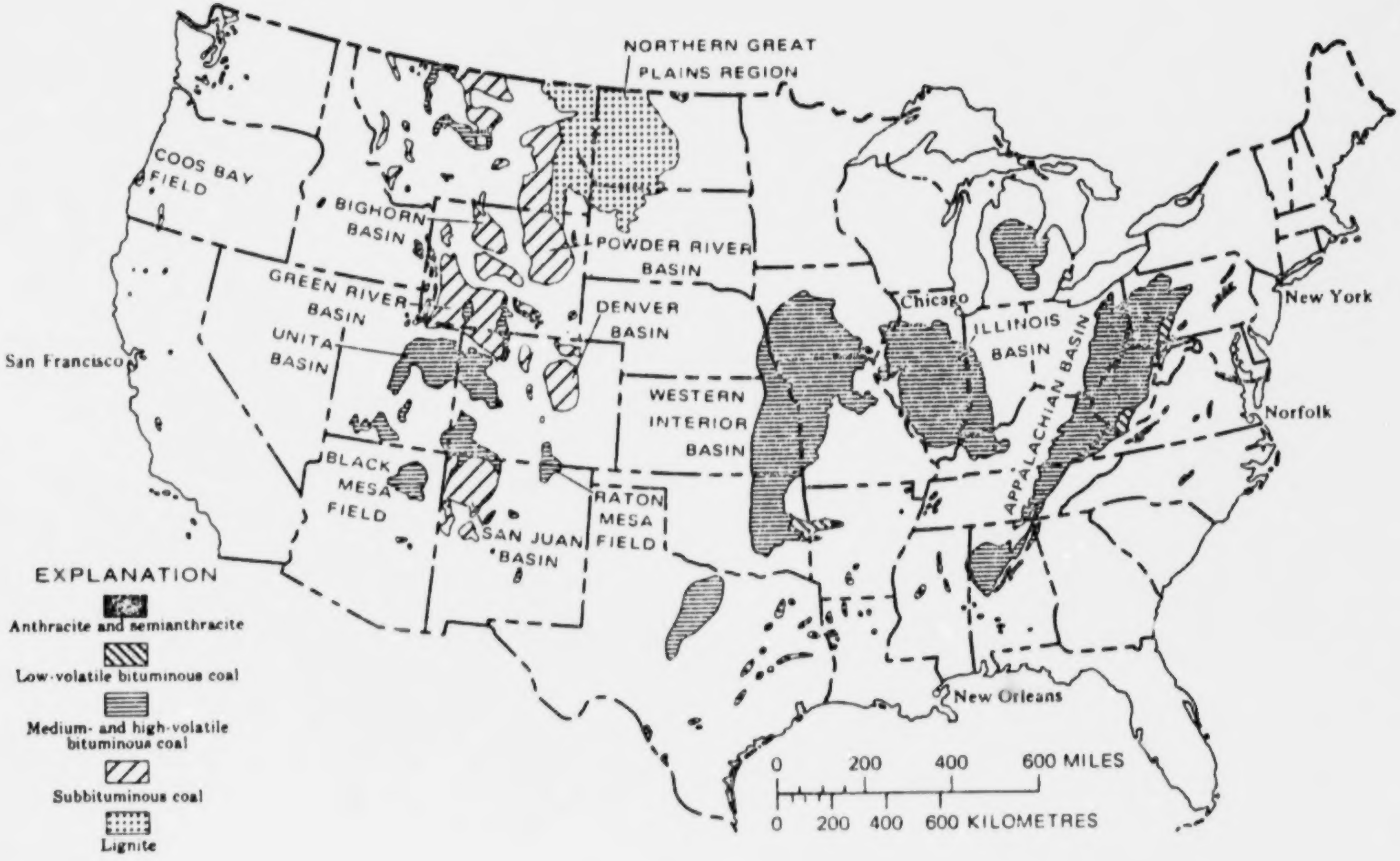
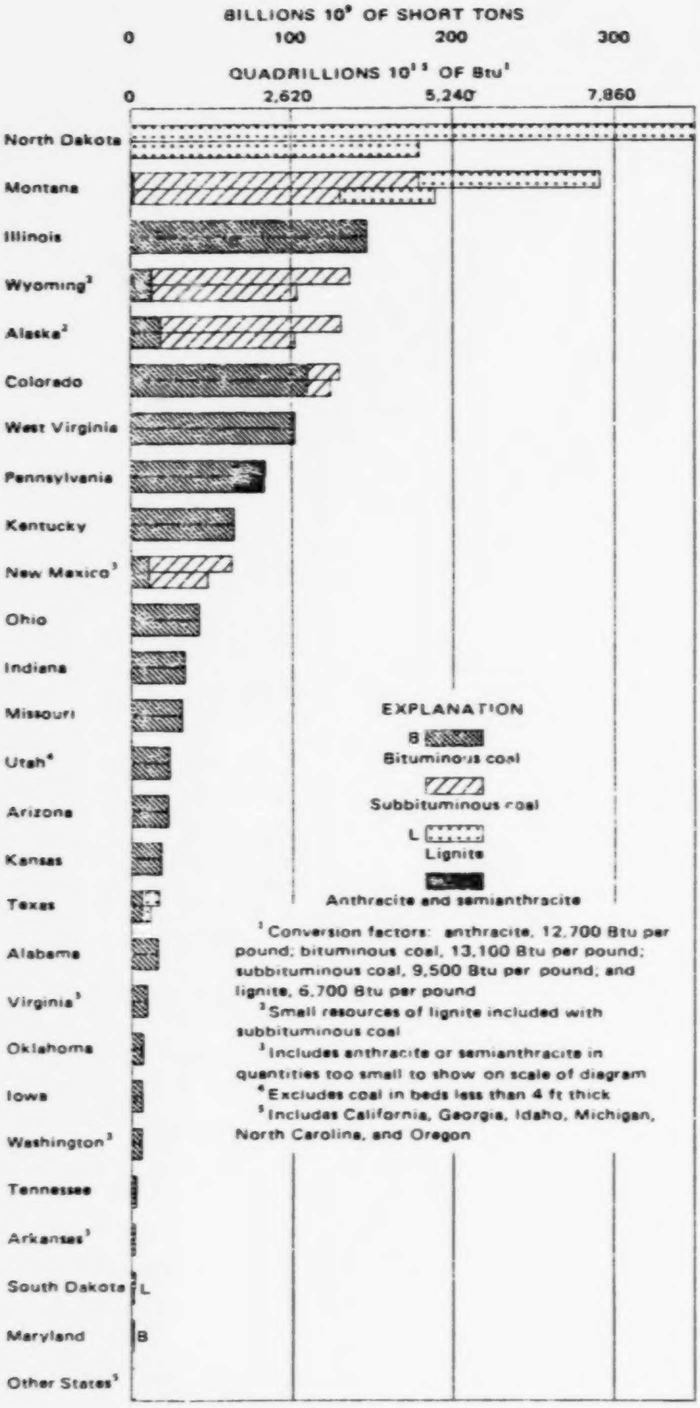

NORTHERN GREAT PLAINS REGION
COOS BAY FIELD
BIGHORN BASIN
POWDER RIVER BASIN
GREEN RIVER BASIN
DENVER BASIN
UNITA BASIN
San Francisco
WESTERN INTERIOR BASIN
BLACK MESA FIELD
RATON MESA FIELD
SAN JUAN BASIN
Chicago
ILLINOIS BASIN
APPALACHIAN BASIN
New York
Norfolk
New Orleans
0 200 400 600 MILES
0 200 400 600 KILOMETRES
EXPLANATION
Anthracite and semianthracite
Low-volatile bituminous coal
Medium- and high-volatile bituminous coal
Subbituminous coal
Lignite

Figure 1. Coal fields of the conterminous United States. (From Averitt, 1975)



[1] Conversion factors: anthracite, 12,700 Btu per pound; bituminous coal, 13,100 Btu per pound; subbituminous coal, 9,500 Btu per pound; and lignite, 6,700 Btu per pound

[2] Small resources of lignite included with subbituminous coal

[3] Includes anthracite or semianthracite in quantities too small to show on scale of diagram

[4] Excludes coal in beds less than 4 ft thick

[5] Includes California, Georgia, Idaho, Michigan, North Carolina, and Oregon

Figure 2. Remaining identified coal resources of the United States - January 1, 1974. (From Averitt, 1975)

In one of the most comprehensive programs of this type, Cavallaro et al. (1976) conducted float-sink tests on 455 coal samples from six regions across the country. Separations were made at three specific gravities (1.3, 1.4, 1.6) and with three top sizes of coal (1-1/2 inch, 3/8 inch, 14 mesh). Without treatment, only 14% of the raw coal samples could meet the pre-1978 emission standard of 1.2 lb SO_2/MBtu, but when treated at 1-1/2-inch top size at 90% Btu recovery, 24% of the samples would meet that standard.

Results by region are summarized in Table 1. Here regional coals vary in total sulfur content from 0.68% to 5.3% sulfur, of which 34% to 68% is pyritic and thus potentially removable if completely liberated from the coal particles. When 3/8-inch top size coals were float-tested at specific gravity 1.6, the ratio of sulfur to calorific value was reduced by 15% to 44%. This meant that additional sulfur removals ranging from none to 78% would be required to meet the emission standard of 1.2 lb SO_2/MBtu. For U.S. coals as a whole, Table 2 shows that the reduction in sulfur emission by gravity flotation could range from 27% to 50% depending on the particle size and the specific gravity of separation.

The more detailed results of this test program further illustrate the variability in sulfur content and in coal cleanability by region, by location within a region, and by coal within a seam. They show that the degree of cleanability and the process arrangements for achieving it can be highly specific and that they may not be reliably inferred from generalized data.

As extensions to the above basic study, other investigations by Giberti et al. (1978), McCreery and Goodman (1978), and Kilgroe (1979) have used the same or similar data as a basis for developing particular perspectives of interest in coal reserves.

TABLE 2. PERCENT REDUCTION OF SULFUR EMISSION

ACHIEVED BY GRAVITY SEPARATION TESTS OF ALL U.S. COALS

	Specific gravity of separation			
	1.6	1.5	1.4	1.3
Particle size	Percent reduction in lb SO_2/MBtu			
1-1/2 in. x 100 mesh	27	30	34	44
3/8 in. x 100 mesh	32	34	38	46
14 mesh x 0	38	40	43	50

Source: Adapted from Cavallaro et al., 1976.

TABLE 1. SULFUR REDUCTION OF U.S. COALS BY GRAVITY SEPARATION
(3/8-inch top size, 1.60 specific gravity)

Region	Sulfur			Lb S/MBtu			
	Percent pyritic	Percent total	Ratio	Raw coal	Float	Percent reduction	SO2 removal needed[a], %
Northern Appalachian (Maryland, Pennsylvania, Ohio, northern and central West Virginia)	2.0	3.0	0.67	4.8	2.7	44	56
Southern Appalachian (Tennessee, Virginia, eastern Kentucky, southern West Virginia)	0.37	1.0	0.36	1.6	1.3	19	8
Alabama	0.69	1.3	0.52	2.0	1.7	15	29
Eastern Midwest (Illinois, Indiana, western Kentucky)	2.3	3.9	0.58	6.5	4.2	35	71
Western Midwest (Arkansas, Iowa, Kansas, Missouri, Oklahoma)	3.6	5.3	0.68	9.0	5.5	39	78
Western (Arizona, Colorado, Montana, New Mexico, North Dakota, Utah, Wyoming)	0.23	0.68	0.34	1.1	0.9	18	none
Total United States	1.9	3.0	0.63	4.9	3.0	39	60

Source: Adapted from Cavallaro et al., 1976.

a. Additional SO_2 removal, as by FGD, to meet emission standard of 1.2 lb SO_2/MBtu.

PREMISES

DESIGN PREMISES

Coal-Cleaning Plant

Plant Premises--

The coal-cleaning plants are assumed to be located at the power plant and are sized to supply the coal demand for a 2000-MW power plant. The PCC plants are based on approximately a 90% Btu recovery for the 5.0% sulfur coal and 6000 hours per year of operation. The CCC plants are based on conversion and loss data supplied by the developers and 8000 hours per year of operation. The cleaning plants have a 15-day raw-coal and a 15-day clean-coal storage based on power plant usage. Oxygen is purchased across the fence and has a 1-day onsite storage. All other chemicals and salable byproducts have 30-day storages.

Waste and Byproduct Management--

PCC plants have closed water circuits and landfill disposal of solid wastes. Refuse is spread, mechanically compacted, and covered with earth daily. A 2-foot final cover is used. Side slopes are restricted to 27 degrees maximum and covered with earth and vegetation is established as the dump increases in height. The disposal site is located one mile from the coal preparation site.

Disposal ponds lined with impervious clay are used to contain the sludge from the CCC and limestone FGD processes. The pond is located one mile from the plant site and it is sized for the 30-year life of the plant.

Power Plant and FGD Premises

Power Plant--

The base-case conditions for coal-cleaning evaluations are a new 2000-MW midwestern power plant with a design heat rate of 9500 Btu/kWh operating at full capacity for 5500 hr/yr. The power plant life is assumed to be 30 years, representing a total of 165,000 hours of operation during the life of the plant.

FGD Comparative Case--

The FGD system used for comparison with the coal-cleaning processes is a limestone scrubbing process with 25% scrubber redundancy, 85% SO_2 removal from the flue gas, and pond sludge disposal located one mile from the power plant. Capital and operating costs are based on the coal-cleaning premises.

Flue Gas Composition--

Flue gas composition is based on the combustion of pulverized coal assuming a total air rate to the air preheater equivalent to 133% of the stoichiometric requirement. This includes 20% excess air to the boiler and 13% air inleakage at the air preheater. A horizontal-fired, coal-burning unit is assumed. It is assumed that 80% of the ash present in the coal is emitted as fly ash, and that 95% of the sulfur in the coal is emitted as sulfur oxides (SO_x). One percent of the sulfur emitted as SO_x is assumed to be SO_3 and the remainder SO_2.

Coal Premises

The coal premises are based on coals with 0.7%, 2.0%, 3.5%, and 5.0% sulfur levels. The composition of the coals is based on composites of 350 to 400 coal samples representing major U.S. coal production areas. The compositional data are summarized in Tables 3 and 4. Raw coal refers to the coal entering the coal-cleaning plant. This coal is supplied in a 3-inch top size after large rocks, mine timbers, and trash have been removed by putting the run-of-mine coal through a rotary breaker and past a tramp iron magnet.

Tyler sieve designations are used for the screen size. For screens successively coarser than three mesh, the width of opening is a continuation of the regular $\sqrt{2}$ series. The resulting coarse sizes fall conveniently close to round numbers in inches.

Broken coal is assumed to have the particle size distribution as represented by the Bennett form of the Rosin and Rammler equation,

$$R = 100e^{-\left(\frac{x}{\bar{x}}\right)^n}$$

which can be plotted on special graph paper, shown in Figure 3, devised by the U.S. Bureau of Mines (1946). In the equation,

x = Particle diameter or width of screen opening in mm. It is the abscissa in Figure 3.

$\bar{x}$ = A size constant in mm which is specific to each distribution line of particle size. In Figure 3 it is the value of x when $R = 36.79\%$; in turn, $R = 36.79\%$ when $\bar{x} = x$ in the Rosin and Rammler equation.

n = A size distribution constant. In Figure 3 it is the arithmetically measured slope of a distribution line. Parallel distribution lines have the same value of n.

e = The base of natural logarithm, namely 2.7183.

R = The weight percentage of coal retained on a screen whose aperture is "x." R expresses cumulative oversize and is the ordinate in Figure 3.

TABLE 3. COMPOSITION OF STUDY COALS - AS RECEIVED BASIS

Coal	Sulfur				Ash, %	Air dry moisture,[a] %	Heat content,[a] Btu	Ultimate analyses			
	Total, %	Pyritic, %	Sulfate, %	Organic, %				C, %	H, %	O, %	N, %
Bituminous, 5.0% sulfur	4.82	3.23	0.06	1.53	16.1	3.5	11,600	63.8	4.2	6.3	1.3
Bituminous, 3.5% sulfur	3.43	2.18	0.05	1.20	13.7	1.9	12,300	70.0	3.9	5.8	1.3
Bituminous, 2.0% sulfur	1.97	1.30	0.04	0.63	14.3	1.2	12,700	71.9	4.1	5.1	1.4
Subbituminous, 0.7% sulfur	0.62	0.21	0.01	0.40	10.1	12.1	10,200	59.7	4.0	12.3	1.2

a. From Cavallaro et al. (1976) and Hamersma and Kraft (1975).
b. From de Lorenzi (1957).

TABLE 4. COMPOSITION OF STUDY COALS - MOISTURE-FREE BASIS

Coal	Sulfur[a]				Ash,[a] %	Heat content,[a] Btu/lb	Ultimate analyses[b]			
	Total, %	Pyritic, %	Sulfate, %	Organic, %			C, %	H, %	O, %	N, %
Bituminous, 5.0% sulfur	5.00	3.35	0.06	1.59	16.7	12,000	66.1	4.4	6.5	1.3
Bituminous, 3.5% sulfur	3.50	2.22	0.05	1.23	14.0	12,500	71.3	4.0	5.9	1.3
Bituminous, 2.0% sulfur	2.00	1.32	0.04	0.64	14.5	12,800	72.8	4.1	5.2	1.4
Subbituminous, 0.7% sulfur	0.70	0.24	0.01	0.45	11.5	11,700	67.9	4.6	14.0	1.3

a. From Cavallaro et al. (1976) and Hamersma and Kraft (1975).
b. From de Lorenzi (1957).

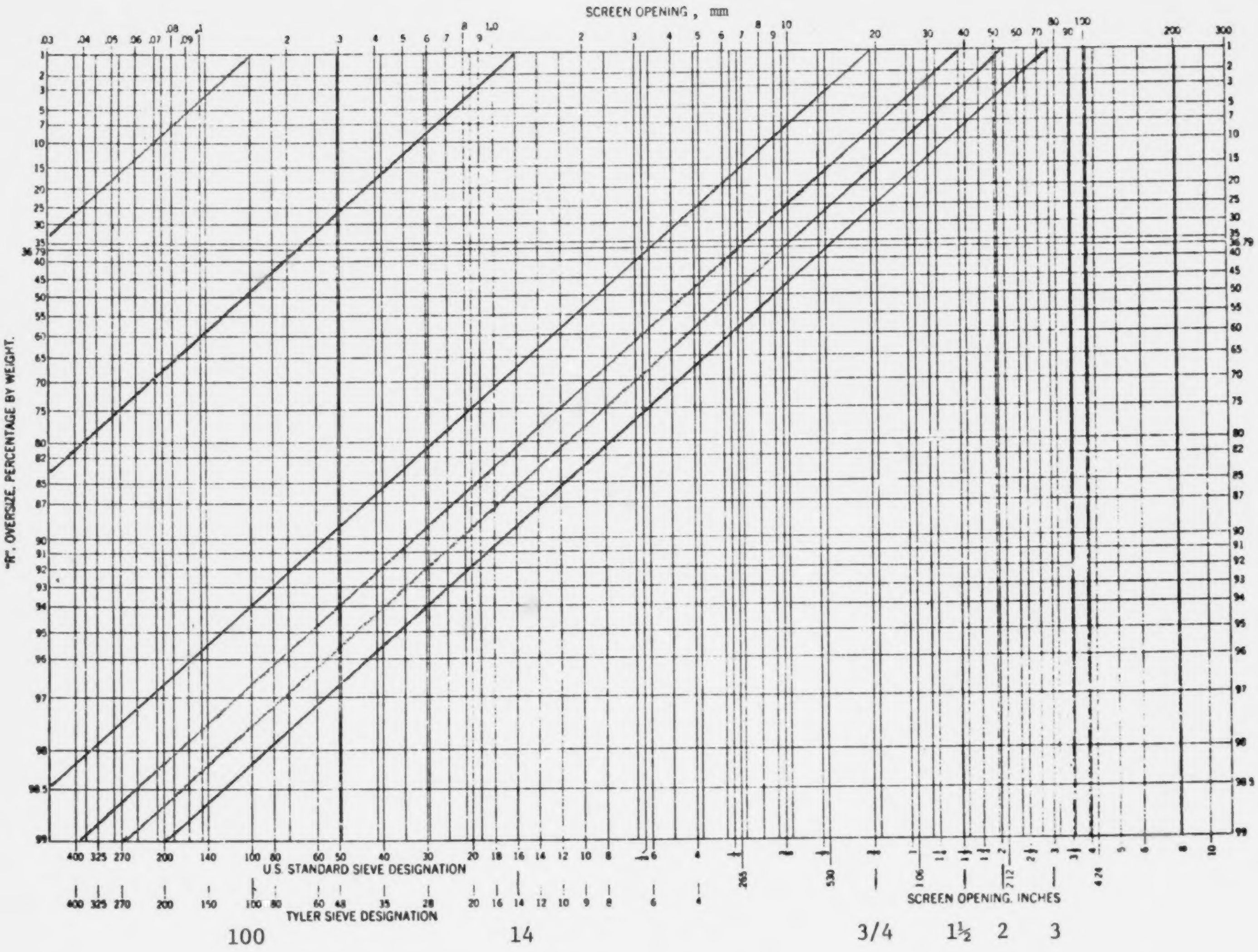


Figure 3. Rosin-Rammler plots of premise coal sizes based on Bureau of Mines, 1946.

For all distribution lines in Figure 3, the value of n is 0.8840. Values of $\bar{x}$ for selected size distribution are given below.

Nominal top sizes	Opening size (Tyler $\sqrt{2}$ Series)		$\bar{x}$
	In.	mm	mm
3 in.	2.970	75.43	13.40
2 in.	2.100	53.34	9.478
1-1/2 in.	1.485	37.71	6.702
3/4 in.	0.742	18.86	3.351
14 mesh	0.046	1.179	0.2094
100 mesh	0.0058	0.147	0.0262

ECONOMIC PREMISES

Project Schedule

The coal-cleaning projects are assumed to begin in mid-1979 and end in mid-1982 with an average capital investment cost basis of the end of 1980. Annual revenue requirements are based on mid-1982 costs.

Capital Investment

Direct Capital Investment--

For each process area in the plant, the direct capital costs include materials and labor for the installation of equipment, piping, instrumentation, electrical requirements, foundations, structures, and buildings. Capital investment costs for services, utilities, and miscellaneous costs are estimated as 6% of the process areas subtotal fixed capital. This covers such items as maintenance shops, stores, communications, railroad, and fire and service water facilities.

Chemical Engineering cost indexes through 1977 and TVA projections of these indexes through 1983 are used to determine direct capital investments. The cost indexes and projections are shown in Table 5.

TABLE 5. COAL-CLEANING COST INDEXES AND PROJECTIONS

Year	1974	1975	1976	1977	1978[a]	1979[a]	1980[a]	1981[a]	1982[a]	1983[a]
Plant[b]	165.4	182.4	192.1	204.1	221.4	240.2	259.4	278.9	299.3	322.3
Material[c]	171.2	194.7	205.8	220.9	240.8	262.5	286.1	309.0	333.7	360.4
Labor[d]	163.3	168.6	174.2	178.2	194.2	209.7	226.5	244.6	264.2	285.3

a. TVA projections.

b. Same as *Chemical Engineering* plant cost index.

c. Same as "equipment, machinery, supports" component of CE plant cost index.

d. Same as "construction labor" component of CE plant cost index.

Source: *Chemical Engineering* (1974-1977)

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Indirect Capital Investment--

Indirect costs consist of in-house engineering design and supervision, architect and engineering contractor expenses, contractor fees, and construction expenses. Construction facilities are considered a part of construction expenses. Consultant fees, if any, are included in contractor costs. The engineering design and supervision, and the contingency factors are based on demonstration-level technology and experience. Indirect investment costs are estimated from the number of drawings required, man-hours of supervision and construction, and other factors related to the complexity of the process.

Capital Investment - Allowances--

Allowances are included for startup and modification, interest during construction, and working capital. Startup and modification allowances are estimated as 10% of the subtotal fixed investment. Interest during construction is estimated as 14% of the subtotal fixed investment for each process.

Working Capital--

Working capital consists of the total amount of money invested in raw materials and supplies carried in stock, finished products in stock, and semifinished products in the process of being manufactured; accounts receivable; cash kept on hand for payment of operating expenses; accounts payable; and taxes payable. For these premises, working capital is defined as the equivalent cost of 3 weeks of raw material costs, 7 weeks of direct operating costs, and 7 weeks of overhead costs. For the PCC processes, the coal discarded in the refuse is not included in working capital since it is assumed that it is lost shortly after it enters the PCC system.

Annual Revenue Requirements

Annual Revenue Requirements - Direct Costs--

Annual Revenue Requirements are based on 5500 hours of operation per year of the utility power plant. Maintenance costs are estimated on the basis of direct investment and are varied for each process according to the relative process complexity and historical experience when available.

Annual Revenue Requirements - Indirect Costs--

Straight-line depreciation of 3.3% per year is used. An interim replacements allowance factor is used in estimating annual revenue requirements to provide for the replacement of short-lived items. An average allowance of about 0.7% of the total investment is provided. An insurance allowance of 0.5% of total depreciable capital investment is also included in the capital charges based on Federal Energy Regulatory Commission practice. Property taxes are estimated as 1.5% of the depreciable capital investment. The depreciation, interim replacement, insurance, and property taxes total 6.0% of the depreciable investment.

Cost of capital and income tax charges of 8.6% are applied to the unrecovered portion of capital investment, based on the debt to equity ratio of 60 to 40, bonds at 10% interest, and a 14% return on equity.

Annual Revenue Requirements - Overheads--

Plant, administrative, and marketing overheads are costs which vary with the type of plant and from company to company. With consideration of the various methods used in industry and illustrated in a variety of cost estimating sources the following method for estimating overheads is used.

Plant overhead is estimated as 50% of the operating labor and supervision since this approximates the actual plant overhead for plants of this size and with these numbers of employees. Administrative overhead is estimated as 10% of operating labor and supervision.

Annual Revenue Requirements - Byproduct Sales--

In estimating annual revenue requirements, credit from sale of byproducts is deducted from the yearly projection of operating cost to obtain the net effect of the coal-cleaning process on the cost of electrical power.

PHYSICAL COAL CLEANING

PROCESS SELECTION

The three PCC processes were selected to represent current commercial technology for high-efficiency coal cleaning. They resulted from the application of conventional coal preparation procedures and techniques, starting with the washability data for the four study coals.

A comprehensive washability analysis, as from a testing laboratory, begins with a screen analysis of a highly representative sample of the raw coal. Each screen fraction then is separated into gravity fractions which are obtained from a series of float-sink tests. For these separations, the screen fraction is immersed and allowed to come to equilibrium in a series of stable dense-medium (DM) liquids whose specific gravities increase in even steps, e.g., 1.30, 1.35, 1.40, ... Finally, each gravity fraction is weighed and analyzed for ash, sulfur (pyritic, organic, and total), and heating value (as Btu/lb). The analytical results are tabulated on a direct basis for each float sample and on a cumulative basis with increasing specific gravity.

In this study, basic washability data were obtained as design premises and were converted to the above standard form. Graphing of appropriate variables disclosed the areas of special sensitivity such as the variation of float weight and of near-gravity material with specific gravity, and the change in separation effectiveness of several items such as sulfur, ash, Btu/lb coal, etc., with particle size.

Interpretation of the washability results suggested 2 inch, 1-1/2 inch, and 3/4 inch as top sizes for the coal separations. As primary separation devices, the DM vessel, DM cyclone, and concentrating table were selected on the basis of commercial usage, efficiency of separation, particle size characteristics, cost, compatibility with other equipment, and the like. For each process, particle size fractions were based on the particle size limitations of the equipment. There are limited options for the treatment of very fine coal and froth flotation was used for this area.

The expected quality of plant separation of coal and impurities was based on equipment performance and the inherent cleanability of the coals. For each item of primary separation equipment and each particle size, equipment performance was indicated by a curve of the proportion of material floated versus the specific gravity of separation. The use of this curve provided for conversion of the washability data, which were obtained under equilibrium conditions, to separation results which can be expected from the plant equipment. Summation of the separation results for the sequence of gravity fractions gave a composite result for the screen fraction processed by that equipment. Compositing among the screen fractions or equipment areas gave integrated results for the process as a whole.

Within each process area associated equipment items such as screens and centrifuges were selected to handle the type of clean coal and refuse from the primary separation equipment in that area. Product and byproduct moisture levels were thereby determined by area. In terms of tonnage rate, each process was sized to produce the moist cleaned coal requirement for a 2000-MW power plant. Attrition of particle size by the mechanical handling of coal was omitted.

PHYSICAL COAL-CLEANING I PROCESS (DM vessel, DM cyclone, froth flotation)

The flow diagram is shown in Figure 4. The material balance and the equipment list are located in Appendix A.

Process Description

Raw Coal Sizing--
The 3 inch x 0 coal from the raw coal stockpile is crushed and screened to 37% 2 inch x 3/8 inch, 55% 3/8 inch x 28 mesh, and 8% 28 mesh x 0. In terms of a Rosin-Rammler chart, the size reduction is from a 3-inch top size to a 2-inch top size, with parallel straight lines of size distribution. However, the 3 inch x 0 raw coal already contains more than the target amount of 2 inch x 3/8 inch material and this fact precludes a simple screening of 2 inch, followed by crushing of the 3 inch x 2 inch fraction to 2 inch x 0. Instead, the raw coal needs to be screened at 1-1/4 inch and the 3 inch x 1-1/4 inch oversize fraction is crushed extensively.

The double-deck coal screen sizes 807 tons/hr of coal at 3 inch x 0 to 95 tons/hr of 3 inch x 1-1/4 inch coal for crushing, 293 tons/hr of 1-1/4 inch x 3/8 inch coal for coarse coal cleaning, and 419 tons/hr of 3/8 inch x 0 coal for finer coal sizing. Nominally, the crushing requirement is the reduction of 95 tons/hr (12% of the head coal). To meet the total sizing requirement, coal from the crusher must contain 5 tons/hr of 2 inch x 3/8 inch, 73 tons/hr of 3/8 inch x 28 mesh, and 17 tons/hr of 28 mesh x 0. The crushing operation, therefore, involves a broad range of size reduction rather than merely reducing the top sizes.

On the fines screens, the 3/8 inch x 0 fractions from raw coal screening and from crushing are screened at 28 mesh. This 28 mesh x 0 undersize fraction is 13% of the feed to the fines screens. To achieve a high degree of screening efficiency on the fines screens, each horizontal vibrating screen is preceded by a sieve bend. In addition to screening, the sieve bend removes much of the wash water from previous screening and thus allows for additional washing on the vibrating screens. The sieve bend or crossflow screen is a stationary screen with no moving

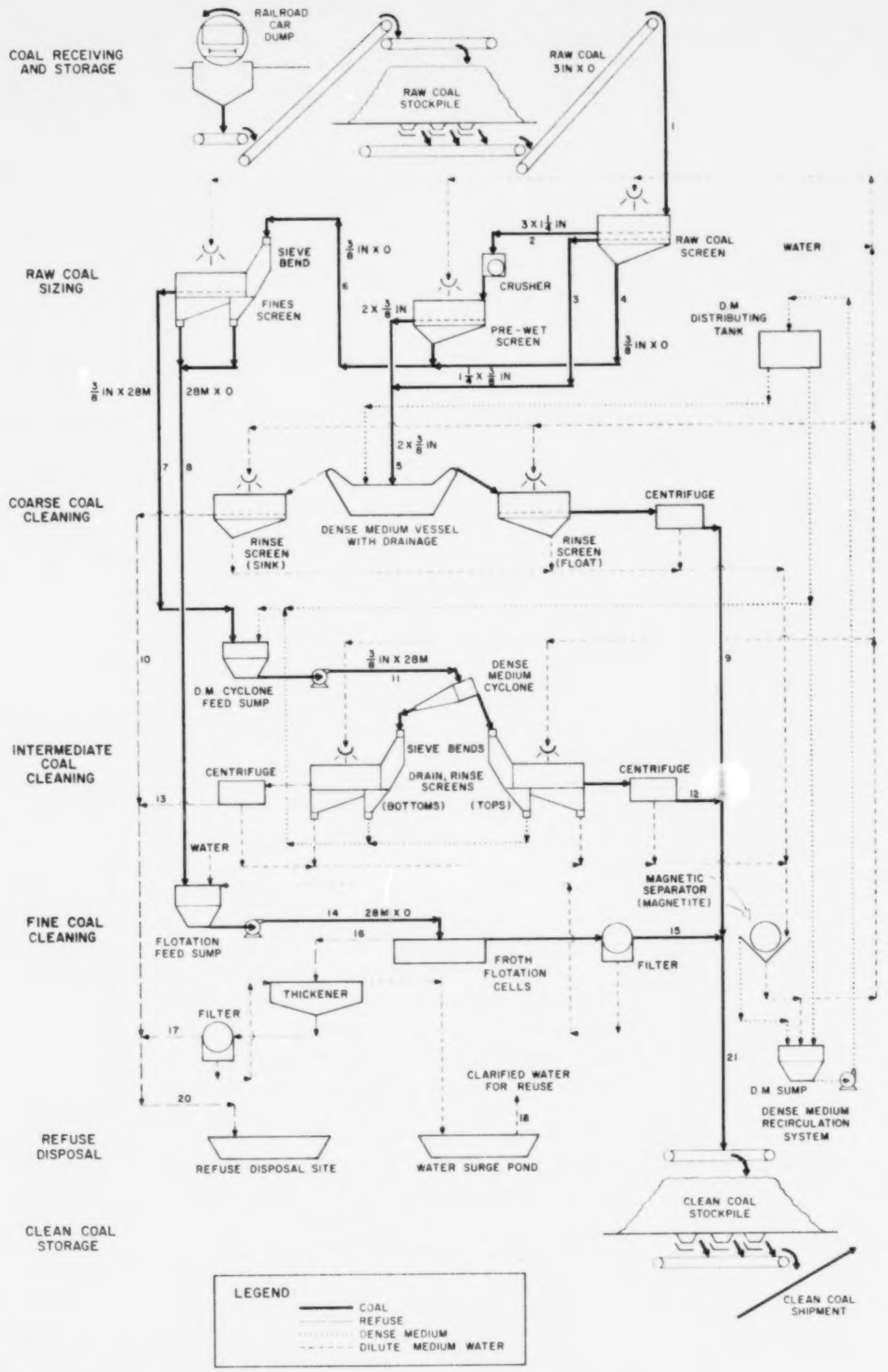

COAL RECEIVING AND STORAGE
RAILROAD CAR DUMP
RAW COAL STOCKPILE
RAW COAL 3 IN X 0
1
RAW COAL SIZING
SIEVE BEND
FINES SCREEN
$\frac{3}{8}$ IN X 0
6
3 X 1$\frac{1}{4}$ IN
2
RAW COAL SCREEN
WATER
CRUSHER
2 X $\frac{3}{8}$ IN
PRE-WET SCREEN
3
4
$\frac{3}{8}$ IN X 0
D.M. DISTRIBUTING TANK
1$\frac{1}{4}$ X $\frac{3}{8}$ IN
$\frac{3}{8}$ IN X 28M
28M X 0
2 X $\frac{3}{8}$ IN
5
7
8
COARSE COAL CLEANING
RINSE SCREEN (SINK)
DENSE MEDIUM VESSEL WITH DRAINAGE
RINSE SCREEN (FLOAT)
CENTRIFUGE
9
10
D.M. CYCLONE FEED SUMP
$\frac{3}{8}$ IN X 28M
11
DENSE MEDIUM CYCLONE
INTERMEDIATE COAL CLEANING
SIEVE BENDS
DRAIN, RINSE SCREENS
(BOTTOMS)
(TOPS)
CENTRIFUGE
13
CENTRIFUGE
12
WATER
MAGNETIC SEPARATOR (MAGNETITE)
FINE COAL CLEANING
FLOTATION FEED SUMP
14
28M X 0
16
FROTH FLOTATION CELLS
15
FILTER
THICKENER
FILTER
17
21
D.M. SUMP
DENSE MEDIUM RECIRCULATION SYSTEM
CLARIFIED WATER FOR REUSE
20
18
REFUSE DISPOSAL
REFUSE DISPOSAL SITE
WATER SURGE POND
CLEAN COAL STORAGE
CLEAN COAL STOCKPILE
CLEAN COAL SHIPMENT
LEGEND
COAL
REFUSE
DENSE MEDIUM
DILUTE MEDIUM WATER

Figure 4. Flow diagram for PCC I process.

parts and requires no connected horsepower. In elevation view, its reversible deck is curved from vertical through a 60° arc to about 30° from the horizontal. The deck is composed of horizontal wedge wires which are accurately spaced for openings as narrow as 0.12 mm. With the crossflow of the coal slurry, the undersize is about one-half the deck opening. At reduced capacity and efficiency, sizing can be as fine as 250 mesh. The 28 mesh sizing in the raw coal sizing section is therefore well within the range of sieve bend application.

Except for surface moisture in the two coarser streams, the screen washing water from the entire raw coal sizing section accumulates in the 28 mesh x 0 stream. This accumulation can be accommodated because the 28 mesh x 0 fraction requires dilution for froth flotation. On this basis, the system can tolerate up to 1.5 - 2 gal/min of wash water for each ton/hr of coal on each screen in the raw coal sizing section.

Coarse Coal Cleaning--

The 2 inch x 3/8 inch coal from the raw coal sizing section is cleaned in a trough-type DM vessel with integral drain screens for clean coal and refuse. A single chain-and-flight conveyor slightly submerges the feed coal in the bath and assists its horizontal movement along several feet of bath length. Clean coal rises as float and refuse sinks toward the bottom of the bath. One strand of the conveyor moves the float fraction up an inclined drain screen for the direct return of excess medium to the bath. The returning strand of conveyor gathers refuse from the floor of the vessel and similarly moves it up an inclined drain screen at the opposite end of the vessel.

In this process, 298 tons/hr of coal are treated in two 7-foot-wide vessels which contain magnetite medium at a specific gravity of 1.55. About 85% of this coal floats and moves along the bath at about 0.2 ft^3/sec/ft of bath width. On the float and sink product rinse screens, vessel products are sprayed with water to reclaim magnetite. The rinse screen decks have 1-mm openings which keep all but the finest coal from entering the dilute medium circuit where it would increase the viscosity. Since the cleaning plant also has DM cyclones which are operated at the same specific gravity as the DM vessels, the magnetite recovery for the two sections is done in a single system. The medium makeup requirement for the vessel is quite low since it replaces only the residual medium adhering to the float and sink products. It also offsets the effect of surface moisture in the incoming coal. For the latter reason, the makeup medium is maintained at a specific gravity of 1.8 to 2.0.

A vibrating basket centrifuge is provided for dewatering the cleaned coal float product to a nominal 2.25% surface moisture. Since the cleaned coal product from the coarse coal cleaning section amounts to only 37% of that from the total plant, the inclusion of this incremental dewatering is a refinement. Centrifuge dewatering of the refuse from the DM vessel is omitted.

Intermediate Coal Cleaning--

DM cyclones are the heart of the cleaning system for the intermediate-sized (3/8 in. x 28 mesh) coal from the raw coal sizing section. Six 24-inch-diameter cyclones are used with the medium at a nominal specific gravity of 1.55. They are preceded by conventional coal-slurry preparation in a pulping tank and are followed by conventional drain-and-rinse screens and by mechanical dewatering of both the cleaned coal and refuse. The DM cyclones produce 55% of the cleaned coal product.

DM cyclone feed is pulped in two parallel feed sumps using moist coal from the raw coal sizing section, return medium from the drain screens, and a small amount of makeup medium. A medium to coal ratio of 5:1 is used in this process but the operating sensitivity would permit a ratio down to about 4:1.

The DM cyclones have a cone angle of 20° and are installed with the longitudinal axis about 10° from horizontal. This positioning minimizes the difference in height between the bottom and top of the cyclone while allowing for drainage during shutdown. The inlet flow rate is about 20 gal/sec/cyclone. The cleaned coal overflow from the cyclones amounts to 84% of the inlet coal, when operated at a specific gravity of 1.55. The separation of coal and refuse to overflow and underflow within the cyclone is also accompanied by a separation of medium allowed for in the operating practice. The effective specific gravity of separation within the cyclone is slightly higher than that of the inlet medium and the specific gravity of the medium in the overflow is definitely lower than that in the underflow. This difference is canceled when the streams of drained medium from the cleaned coal and the refuse are recombined.

The drain screens are sieve bends with 1-mm openings (for 32 mesh retention) which maintain the 3/8 inch x 28 mesh material as oversize but permit free passage of 325 mesh x 0 magnetite and water. For the same effective size retention, the decks of the horizontal vibrating rinse screens have 0.5-mm openings.

Vibrating basket centrifuges are used for mechanical dewatering of both the cleaned coal and refuse products from DM cyclone cleaning. Since both products are nominally free of 28 mesh x 0 material, a surface moisture of 5.25% is used for the cleaned coal from this section.

Dilute medium effluent from the rinse screens is reconstituted to a specific gravity above 1.55 by magnetic separators. The two tandem magnetic rolls or drums, 30 inch diameter x 10 feet long and containing permanent magnets, are mounted horizontally and slowly rotated to pick up magnetite. It is scraped from the drums as a thick slurry and diluted to the nominal specific gravity. Because of pumping heads, the magnetic separators are mounted on an upper floor and the dilute medium is pumped to that elevation. The dense medium is then handled by gravity flow.

Fine Coal Cleaning--

The 28 mesh x 0 fine coal fraction from the raw coal sizing section amounts to 66 tons/hr or 8% of the raw coal to the cleaning plant. It contributes an important increment to the Btu recovery of the cleaning plant but cleaned coal quality is less critical in the fine coal cleaning section than in the major sections. For this reason, single-stage flotation is used on the entire fraction--supplementary cleaning with hydrocyclones, etc., is omitted.

For flotation feed, a pulp density of 10% solids is formed in the flotation feed sump by diluting the 28 mesh x 0 coal slurry with part of the filtrate from the flotation clean coal filter. Except for cell capacity, the pulp density of the flotation feed is not critical and could be reduced to 5% solids. However, at fixed cell capacity such dilution would reduce the residence time in the cells and lower the recovery.

Cleaned coal concentrate from the flotation overflow at about 20% solids is filtered on a continuous rotary vacuum disk filter which reduces the surface moisture to about 25%. The pulp density of the flotation underflow can be as low as 3% solids because a majority of the cell feed water occurs in the underflow. This stream flows to a thickener whose underflow is filtered on a disk filter. Since the refuse filtrate can contain slimes, this filter is operated in closed circuit with the thickener. Thickener overflow and residual filtrate from the cleaned coal filter flow to a clarified water tank or pond from which water is pumped for reuse in the plant.

Cleaning Performance

The cleaning performance of the PCC I process is shown in Table 6 for the four premise coals. Features of cleaning performance are discussed along with those of other processes in the Results section of the report.

PHYSICAL COAL-CLEANING II PROCESS (Low-gravity and moderate-gravity DM cyclones, froth flotation)

The flow diagram is shown in Figure 5. The material balance and the equipment list are located in Appendix A.

Process Description

Raw Coal Sizing--

The entire feed stream of raw coal first is reduced by screening and crushing from 3 inch x 0 to 3/4 inch x 0. The fine coal fraction of 28 mesh x 0 then is removed to provide two product streams for subsequent cleaning at 3/4 inch x 28 mesh and at 28 mesh x 0. Under the project premises, the size distributions of the 3-inch top size and the 3/4-inch top size coals are parallel straight lines on a Rosin-Rammler chart. This means that the crushing from the 3-inch to the 3/4-inch level involves a reduction in the full range of particle sizes rather

TABLE 6. CLEANING PERFORMANCE OF PCC I PROCESS

DM VESSEL, DM CYCLONE, AND FROTH FLOTATION

(MOISTURE-FREE BASIS)

	0.7% sulfur coal		2.0% sulfur coal		3.5% sulfur coal		5.0% sulfur coal	
	Raw coal	Product	Raw coal	Product	Raw coal	Product	Raw coal	Product
Total sulfur, %	0.70	0.62	2.00	1.36	3.50	2.55	5.00	3.67
Pyritic sulfur, %	0.24	0.16	1.32	0.68	2.22	1.27	3.35	2.02
Ash, %	11.5	7.9	14.5	7.5	14.0	8.0	16.7	10.1
Btu/lb	11,700	12,200	13,000	14,000	12,700	13,600	12,000	13,000
Btu recovery, %	-	95.1	-	93.1	-	92.2	-	90.7
Weight recovery, %	-	91.1	-	86.0	-	86.2	-	84.2
Total sulfur, lb/MBtu	0.60	0.51	1.54	0.97	2.76	1.87	4.17	2.84
Sulfur removal, % Btu basis	-	15	-	37	-	32	-	32

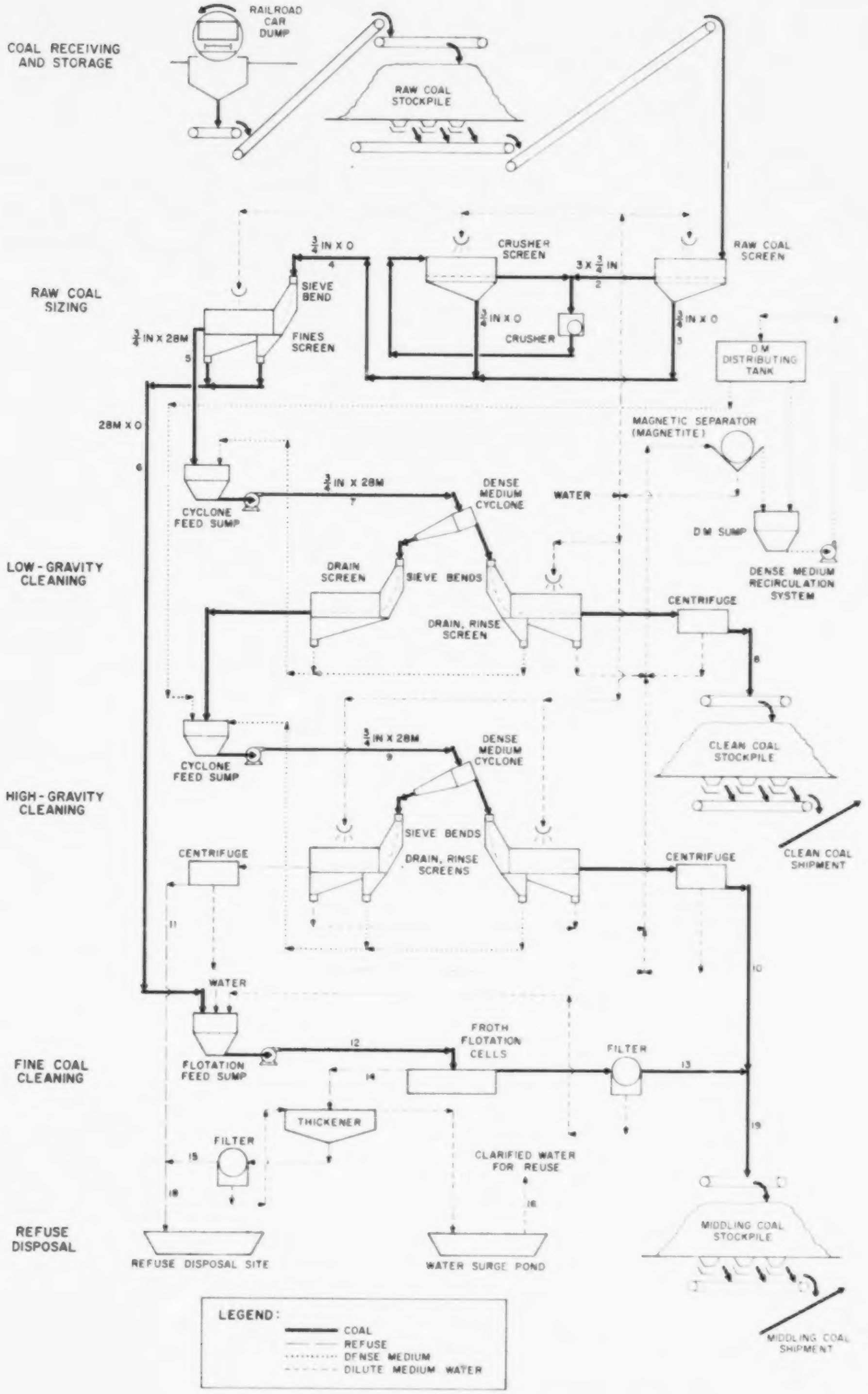

COAL RECEIVING AND STORAGE
RAILROAD CAR DUMP
RAW COAL STOCKPILE
1
RAW COAL SIZING
3/4 IN X 0
4
CRUSHER SCREEN
3 X 3/4 IN
2
RAW COAL SCREEN
SIEVE BEND
3/4 IN X 28M
5
FINES SCREEN
3/4 IN X 0
CRUSHER
3/4 IN X 0
3
DM DISTRIBUTING TANK
28M X 0
6
MAGNETIC SEPARATOR (MAGNETITE)
CYCLONE FEED SUMP
3/4 IN X 28M
7
DENSE MEDIUM CYCLONE
WATER
DM SUMP
DENSE MEDIUM RECIRCULATION SYSTEM
LOW-GRAVITY CLEANING
DRAIN SCREEN
SIEVE BENDS
DRAIN, RINSE SCREEN
CENTRIFUGE
8
CLEAN COAL STOCKPILE
CYCLONE FEED SUMP
3/4 IN X 28M
9
DENSE MEDIUM CYCLONE
HIGH-GRAVITY CLEANING
SIEVE BENDS
DRAIN, RINSE SCREENS
CENTRIFUGE
CENTRIFUGE
CLEAN COAL SHIPMENT
11
10
WATER
FINE COAL CLEANING
FLOTATION FEED SUMP
12
FROTH FLOTATION CELLS
14
FILTER
13
THICKENER
FILTER
15
19
CLARIFIED WATER FOR REUSE
18
16
REFUSE DISPOSAL
REFUSE DISPOSAL SITE
WATER SURGE POND
MIDDLING COAL STOCKPILE
MIDDLING COAL SHIPMENT
LEGEND:
COAL
REFUSE
DENSE MEDIUM
DILUTE MEDIUM WATER

Figure 5. Flow diagram for PCC II process.

than merely crushing to a minus 3-inch size. The 3/4 inch x 0 coal contains 81% 3/4 inch x 28 mesh and 19% 28 mesh x 0 particles.

To achieve the above shift in coal size, the raw coal sizing section begins with a vibrating raw coal screen to remove material which is already at 3/4 inch × 0 and does not require crushing. Of the 804 tons/hr of feed, this undersize fraction amounts to 596 tons/hr. However, the crushing operation is intensive. It must reduce 3 inch x 3/4 inch coal to 3/4 inch x 0 and it must also provide the size distribution required. After allowing for the 28 mesh x 0 component in the 3/4 inch x 0 undersize from raw coal screening, the crushing is adjusted to reduce 208 tons/hr of 3 inch x 3/4 inch coal to 102 tons/hr at 3/4 inch x 28 mesh and 106 tons/hr at 28 mesh x 0. A vibrating screen in closed circuit with the crusher controls the top size of crushed coal at 3/4 inch.

Next, the entire stream of 3/4 inch x 0 coal (the combined undersize coal from the raw coal and crusher screens) is separated on the fines screens to 3/4 inch x 28 mesh and 28 mesh x 0 fractions for separate treatments in the coal-cleaning sections. The horizontal vibrating fines screen for this separation is preceded by a sieve bend with slot openings of 1.2 mm which pass a major portion of the 28 mesh x 0 fines and provide for substantial dewatering of the sieve bend oversize material. This water is from washing on the raw coal and crusher screens; its removal allows for additional washing and more effective screening on the fines screen. The latter screen provides a sufficiently fines-free oversize at 3/4 inch x 28 mesh for cleaning in the DM cyclone section.

Undersize coal and the wash water from the sieve bend and the horizontal fines screen are combined to a 28 mesh x 0 slurry for transfer to feed makeup in the fine coal cleaning section. Since the froth flotation feed in the fine coal cleaning section will be diluted to about 10% solids and since the fine coal cleaning section is relatively large, there is ample latitude of water use for screen washing in the raw coal sizing section.

Low-Gravity Cleaning--

In this section a DM cyclone is operated at the lowest practical specific gravity for the production of a limited tonnage of unusually clean coal. This product has very low ash and pyritic sulfur contents and a correspondingly high heating value. Weight recovery and Btu recovery are sacrificed in favor of this high quality.

To achieve the above objectives, the low-gravity DM cyclone is operated at a specific gravity of 1.34. Below this specific gravity level the commercial experience with magnetite slurry in DM cyclones appears too limited for specification for the treatment of various coals in various makes of cyclones. The limitation comes not in the preparation of a magnetite slurry at lower specific gravity but in instability of the specific gravity and hence of separation within the cyclone. The low-gravity cyclone of this process is considered commercially stable and without unusual sensitivities.

In terms of equipment, 648 tons/hr of moist 3/4 inch x 28 mesh coal from the raw coal sizing section enters two conical cyclone feed sumps which are operated in parallel. Return medium from the cyclone drain screens and some makeup medium are added to the feed sumps to produce a medium to coal ratio of 5:1 (a ratio between 5:1 and 4:1 is fully operable). This feed slurry is pumped to a bank of six 28-inch-diameter cyclones for separation at a specific gravity of 1.34. At this gravity, only 49% (315 tons/hr) of the cyclone feed coal reports as cyclone overflow. It is drained first on a sieve bend with 1-mm openings and next on a vibrating screen with deck openings of 0.5 mm. Both openings retain the 28-mesh coal for water rinsing on another section of the same vibrating screen. Mechanical dewatering of the rinsed coal is done in a vibrating basket centrifuge. Since the clean coal is at 3/4 inch x 28 mesh and nominally free of 28 mesh x 0 material, a surface moisture of 4% can be expected.

Underflow from the DM cyclone is drained on a sieve bend with 1-mm openings and a vibrating screen with deck openings of 0.5 mm. Since the drained underflow will be cleaned at a higher specific gravity in the following cleaning section, they are not rinsed in the low-gravity cleaning section. Medium drained from the overflow and underflow drain screens is combined and returned to the cyclone feed sump but the dilute medium from clean coal rinsing and dewatering is pumped to magnetic separators for reconstituting of magnetite medium to a specific gravity of 1.34.

Normal-Gravity Cleaning--

Since the feed to this cleaning section is the drained underflow from the low-gravity cyclone, the two sections operate partially in series. The high-gravity cleaning will remove sufficient refuse to produce a middling grade of cleaned coal and in so doing it leads to a Btu recovery of at least 90% for the process as a whole. For the base-case coal, these requirements call for a specific gravity of 1.55 in the high-gravity cyclone.

The equipment for high-gravity cleaning is similar to that used in the other DM cyclone separations. Cyclone feed is prepared in two conical cyclone feed sumps which receive 333 tons/hr of moist coal underflow from the low-gravity cyclone. The surface moisture of this coal is residual magnetite medium at a specific gravity of 1.34. Drained medium from this sections's drain screens (specific gravity 1.55) and makeup medium are added to the feed sumps to produce a cyclone feed with a medium to coal ratio of 5:1.

The DM cyclone capacities call for six 22-inch-diameter high-gravity cyclones, though this size is less common than 20-, 24-, and 28-inch-diameter units. An even number of cyclones is preferred for grouping with other equipment in the section. Cyclones are of standard material and are conventionally mounted with the longitudinal axis about 10° from the horizontal.

Overflow from the cyclone is drained of medium on a sieve bend with 1-mm openings and on a horizontal vibrating screen with 0.5-mm openings.

Water rinsing is done on another section of the same screen. Mechanical dewatering is done in a vibrating basket centrifuge. Underflow refuse from the high-gravity cyclones is drained, rinsed, and dewatered on equipment similar to, but of lower capacity than, that used on the overflow side of the high-gravity cyclone.

Fine Coal Cleaning--

Since the raw coal was reduced in the raw coal sizing section to the relatively small top size of 3/4 inch, the 28 mesh x 0 fine coal fraction is proportionately large--it is 19% of the raw coal feed or 156 tons/hr. Conventional froth flotation is used for this fine coal cleaning.

Flotation feed is pulped in the flotation feed sump which receives 28 mesh x 0 coal slurry from the raw coal sizing section and return water from the flotation section. This return water includes most of the filtrate from the section's cleaned coal filter and most of the overflow from the flotation underflow thickener. A limited amount of clarified water also is used to produce a pulp density of 10% solids in the flotation feed. The flotation overflow of relatively clean coal is filtered on a continuous rotary vacuum disk filter which reduces the surface moisture to about 25%. Since the cleaned coal product from flotation is of lower quality than the highly cleaned coal from the low-gravity cyclone, it is added to the middling coal product from the high-gravity cleaning section. This disposition of the flotation coal upgrades the total middling product without debasing the highly cleaned product.

Flotation underflow (which may be as dilute as 3% solids) is routed to a thickener whose underflow is filtered on a disk filter. For improved control of slimes, the refuse filtrate is returned to the thickener for additional settling.

Cleaning Performance and Base-Case Costs

Cleaning performance for the total process and for its clean coal and middling sections is shown in Table 7, on a moisture-free basis, for the four premise coals. Since the first DM cyclone is operated at a nominal minimum specific gravity of 1.34, the clean coal represents the cleanest product and greatest pyrite removal available from these coals at a 3/4-inch top size. The moderate gravity of 1.55 in the second cyclone releases enough refuse to maintain a high overall thermal recovery and to produce a middling product of intermediate quality between the raw and clean coals. Other features of cleaning performance are discussed in the Results section.

PHYSICAL COAL-CLEANING III PROCESS (DM cyclone, concentrating table)

The flow diagram is shown in Figure 6. The material balance and the equipment list are located in Appendix A.

TABLE 7. CLEANING PERFORMANCE OF PCC II PROCESS

LOW-GRAVITY AND MODERATE-GRAVITY DM CYCLONES, FROTH FLOTATION

(MOISTURE-FREE BASIS)

	0.7% sulfur coal				2% sulfur coal			
	Raw coal	Clean coal	Midd-ling	Total product	Raw coal	Clean coal	Midd-ling	Total product
Total sulfur, %	0.70	0.57	0.66	0.62	2.00	1.09	1.59	1.33
Pyritic sulfur, %	0.24	0.11	0.20	0.16	1.32	0.41	0.91	0.65
Ash, %	11.5	5.4	9.5	7.4	14.5	4.55	9.95	7.1
Btu/lb	11,700	12,600	12,000	12,300	13,000	14,500	13,600	14,100
Btu recovery, %	-	49.3	46.0	95.3	-	50.1	42.8	92.9
Weight recovery, %	-	46.0	44.9	90.9	-	44.8	40.7	85.5
Total sulfur, lb/MBtu	0.60	0.45	0.56	0.50	1.54	0.76	1.16	0.94
Sulfur removal, % Btu basis	-	24	6	17	-	51	25	39

	3.5% sulfur coal				5% sulfur coal			
	Raw coal	Clean coal	Midd-ling	Total product	Raw coal	Clean coal	Midd-ling	Total product
Total sulfur, %	3.50	2.10	2.89	2.50	5.00	2.96	3.98	3.51
Pyritic sulfur, %	2.22	0.82	1.61	1.22	3.35	1.31	2.33	1.86
Ash, %	14.0	5.2	10.2	7.7	16.7	6.5	11.6	9.3
Btu/lb	12,700	14,050	13,300	13,700	12,000	13,500	12,700	13,100
Btu recovery, %	-	47.1	45.0	92.1	-	43.9	47.50	91.4
Weight recovery, %	-	42.7	43.1	85.8	-	39.2	44.8	84.0
Total sulfur, lb/MBtu	2.76	1.49	2.17	1.83	4.17	2.19	3.13	2.68
Sulfur removal, % Btu basis	-	46	21	34	-	47	25	36

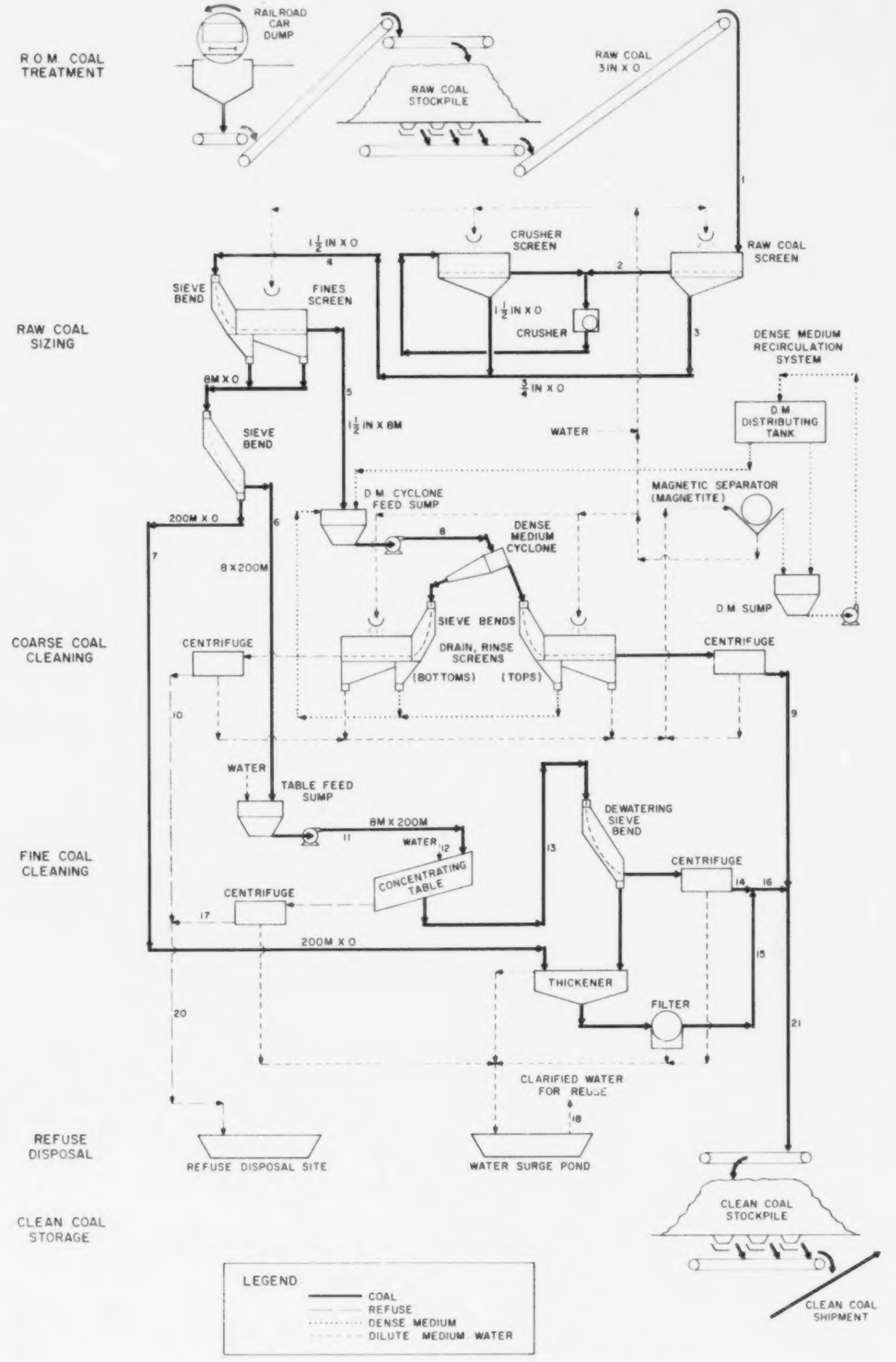

R O M COAL TREATMENT
RAILROAD CAR DUMP
RAW COAL STOCKPILE
RAW COAL 3IN X 0
1
RAW COAL SIZING
$1\frac{1}{2}$ IN X 0
4
CRUSHER SCREEN
2
RAW COAL SCREEN
SIEVE BEND
FINES SCREEN
$1\frac{1}{2}$ IN X 0
CRUSHER
3
DENSE MEDIUM RECIRCULATION SYSTEM
8M X 0
5
$\frac{3}{4}$ IN X 0
SIEVE BEND
$1\frac{1}{2}$ IN X 8M
WATER
D M DISTRIBUTING TANK
MAGNETIC SEPARATOR (MAGNETITE)
D M CYCLONE FEED SUMP
200M X 0
6
8
DENSE MEDIUM CYCLONE
7
8 X 200M
D M SUMP
COARSE COAL CLEANING
CENTRIFUGE
SIEVE BENDS
DRAIN, RINSE SCREENS
(BOTTOMS)
(TOPS)
CENTRIFUGE
10
9
WATER
TABLE FEED SUMP
DEWATERING SIEVE BEND
8M X 200M
11
WATER
12
13
FINE COAL CLEANING
CONCENTRATING TABLE
CENTRIFUGE
CENTRIFUGE
14
16
17
200M X 0
15
THICKENER
FILTER
20
21
CLARIFIED WATER FOR REUSE
18
REFUSE DISPOSAL
REFUSE DISPOSAL SITE
WATER SURGE POND
CLEAN COAL STORAGE
CLEAN COAL STOCKPILE
CLEAN COAL SHIPMENT
LEGEND
COAL
REFUSE
DENSE MEDIUM
DILUTE MEDIUM WATER

Figure 6. Flow diagram for PCC III process.

Process Description

Raw Coal Sizing--

In this process the twofold purpose of raw coal sizing is the production of 1-1/2 inch x 0 coal at the desired size distribution, followed by its separation into size fractions of 67% at 1-1/2 inch x 8 mesh, 31% at 8 mesh x 200 mesh, and 2% at 200 mesh x 0. Since the 3 inch x 0 raw coal from stockpile contains more than the target amount of 1-1/2 inch x 8 mesh material, the raw coal screens are set at 3/4 inch and deliver at undersize of 65% at 3/4 inch x 0. This screen size allows for a realistic size distribution of crushed coal when the 3 inch x 3/4 inch oversize is crushed in closed circuit to 1-1/2 inch x 0.

The fines screens are compound units, each having a sieve bend followed by a horizontal vibrating screen. The sieve bend removes excess water from the upstream screening and it performs an important part of the screening at 8 mesh. On this basis, the vibrating fines screens can be washed liberally to remove the remaining 8 mesh x 0 fraction. As a further aid to the fine coal screening, the 3/4 inch x 0 fraction from the raw coal screens and the 1-1/2 inch x 0 fraction from crushing are conveyed and screened separately at 8 mesh. This provides some balance on the fines screens among tonnage rate, top size, and amount of undersize to be washed through the screens.

Following the fines screens, sieve bends are used to separate the majority of the accumulated water and 200 mesh x 0 material from the 8 mesh x 0 fraction. The sharpness of this separation is not critical since its purpose is to avoid an excess of water and slimes in the 8 mesh x 200 mesh feed to the concentrating tables. The 200 mesh x 0 fraction is routed to a thickener. In the material balance, a sharp separation at 200 mesh was assumed but in practice the sieve bend openings could be set at, say, 150 mesh to achieve the needed amount of water and fines removal at a higher screening efficiency. This latitude is available from the performance characteristics of the concentrating table.

Coarse Coal Cleaning--

The 1-1/2 inch x 8 mesh fraction is cleaned in DM cyclones followed by conventional drain-and-rinse screening and by mechanical dewatering of the cleaned coal and refuse products. Cyclone feed is prepared in the cyclone feed sump which serves as a pulping tank for the incoming coal, the medium recirculated from the drain screens, and some makeup medium. In this process the DM cyclone circuit is designed to operate at a specific gravity of 1.55 and the recirculated medium returns to the pulping tank at that value. However, the makeup medium is maintained at a somewhat higher specific gravity (1.8 to 2.0) to offset the residual moisture in the coal from the fines screens.

On a weight basis, the feed to the cyclone has a medium to coal ratio of 5:1 and, in turn, the medium contains about 44% magnetite when the specific gravity of the medium is 1.55. This means that the cyclone feed contains 19% coal, 71% water, and 11% magnetite and it emphasizes the relatively high loading of medium which is handled on a recirculated basis in the DM cyclone section. The cyclones are large (28-in. diameter), of standard design, and mounted with the longitudinal axis about 10° from horizontal.

The clean coal overflow and the refuse underflow are drained on similar sieve bends with openings of 1 mm. These small openings prevent the escape of fine coal (down to 32 mesh) to the drained medium where it would cause an increase in viscosity. At the same time, the sieve bends permit free passage of the 325 mesh x 0 magnetite particles which are essentially smaller than 0.043 mm. Drained medium is returned to the feed pulping tank but rinse water from the vibrating rinse screens is routed to a two-stage magnetic separator for the recovery of 99.8% of the magnetite. Magnetite concentrate is returned to the feed pulping tank and the rinse water is used for washing in the raw coal sizing section. Both refuse and cleaned coal are dewatered in vibrating basket centrifuges to a surface moisture of 3.5%. This relatively low moisture level results from the absence of 28 mesh x 0 particles and from the particle size range in the 1-1/2 inch x 28 mesh product.

Fine Coal Cleaning--

The fine coal from the raw coal sizing section consists of a major stream (250 tons/hr) at 8 mesh x 200 mesh and a minor stream (15 tons/hr) at 200 mesh x 0. The 8 mesh x 200 mesh fraction is cleaned by tabling. The 200 mesh x 0 fraction is thickened without cleaning, filtered, and added to the cleaned coal product. Since the 200 mesh x 0 fraction contains most of the screen washing water from the raw coal sizing section, it is excluded from table feed makeup as a precaution against excessive dilution of the table feed pulp. This arrangement provides operating latitude for ample washing of raw coal sizing screens under adverse screening conditions. Also, the 200 mesh x 0 size is not advantageous in this table feed. Tabling does not provide ash removal below 100 mesh and the premise coals do not contain significant pyrite at extremely fine sizes.

The 8 mesh x 200 mesh coal for tabling is diluted in the table feed sump to a water to coal ratio of 1-1/2:1. This table feed pulp is delivered to six revolving feed distributors, each of which supplies six table decks with a constant rate of pulp at uniform pulp density. The concentrating tables are arranged in nine units, each four decks high. The relatively large bank of 36 decks corresponds to a capacity of about 7 tons per hour per deck. This capacity is conservatively lower than the often-quoted 12.5 tons per hour per deck which is associated with much coarser feed.

Dressing water is added along the top edge of the table to provide stable flow across its deck. Including dressing water, the total water to coal ratio is 2:1. Since about 90% of the water to the table overflows with the cleaned coal concentrate, the cleaned coal is at low pulp density. It is partially dewatered on a sieve bend with openings to retain 200 mesh solids. Sieve bend overflow is then dewatered in vibrating basket centrifuges which reduce the surface moisture of the cleaned coal to about 6.5%. Sieve bend filtrate is added, along with the 200 mesh x

0 fraction, to a thickener whose underflow is filtered on a disk filter. A part of this filtrate may be used directly in the table feed sump.

Table refuse is essentially free of slimes and it is dewatered in vibrating basket centrifuges. Refuse centrate, along with thickener overflow, goes to the clarified water pond or tank, but the process latitude allows for routing the refuse centrate to the thickener if operating conditions produce excessive solids in the centrate.

Cleaning Performance

The cleaning performance of the PCC III process is shown in Table 8 for the four premise coals. It is compared with those of the other processes in the Results section.

TABLE 8. CLEANING PERFORMANCE OF PCC III PROCESS

DM CYCLONE, CONCENTRATING TABLE

(MOISTURE-FREE BASIS)

	0.7% sulfur coal		2.0% sulfur coal		3.5% sulfur coal		5.0% sulfur coal	
	Raw coal	Product	Raw coal	Product	Raw coal	Product	Raw coal	Product
Total sulfur, %	0.70	0.63	2.00	1.42	3.50	2.63	5.00	3.78
Pyritic sulfur, %	0.24	0.17	1.32	0.74	2.22	1.35	3.35	2.13
Ash, %	11.5	8.1	14.5	8.1	14.0	8.5	16.7	10.6
Btu/lb	11,700	12,200	13,300	13,900	12,700	13,600	12,000	12,900
Btu recovery, %	-	94.6	-	93.0	-	92.2	-	90.7
Weight recovery, %	-	90.9	-	86.4	-	86.7	-	84.7
Total sulfur, lb/MBtu	0.60	0.52	1.54	1.02	2.76	1.94	4.17	2.93
Sulfur removal, % Btu basis	-	13	-	34	-	29	-	30

CHEMICAL COAL CLEANING

KVB CHEMICAL COAL-CLEANING PROCESS

The flow diagram is shown in Figure 7. The base-case material balance and equipment list are located in Appendix A.

Process Description

This process is the result of several years of research in chemical desulfurization of fuels by KVB (Diaz and Guth, 1975; Guth, 1978; KVB, 1977). The developer claims the process removes 95% to 99% of the pyritic sulfur and up to 40% of the organic sulfur. It uses the technology of selective oxidation and extraction of sulfur compounds in fuels covered by KVB patents. This process was patented in September 1975 and has been demonstrated in bench-scale equipment only.

The process consists of a selective oxidation of the sulfur compounds in the coal using gaseous NO_2 in the presence of O_2 at low temperatures and atmospheric pressure. The organic sulfur reaction is not fully understood. The pyritic sulfur reaction consists of:

$$FeS_2 + 6NO_2 \rightarrow FeSO_4 + SO_2 + 6NO$$

$$6NO + 3O_2 \rightarrow 6NO_2$$

The reaction is exothermic but does not provide sufficient heat to maintain the reaction temperature. The pyrite oxidation is carried out at a low O_2 concentration so that the reaction effluent gas is virtually free of NO_2. The O_2 is consumed by reaction with NO to form NO_2. The NO_2 reacts to oxidize the coal sulfur forming SO_2 and NO. The reactor effluent gas is very low in NO_2 and O_2 (about 1000 ppm each) and high in NO.

The sulfates are removed from the coal by reaction with NaOH and washing with hot water. The reactions are:

$$2[R]\text{-sulfate} + NaOH \rightarrow 2[R]H + 2Na_2SO_4$$

$$2FeSO_4 + 4NaOH + 2H_2O \rightarrow 2Fe(OH)_3 + 2Na_2SO_4 + H_2$$

Where [R] is the organic radical in the coal matrix.

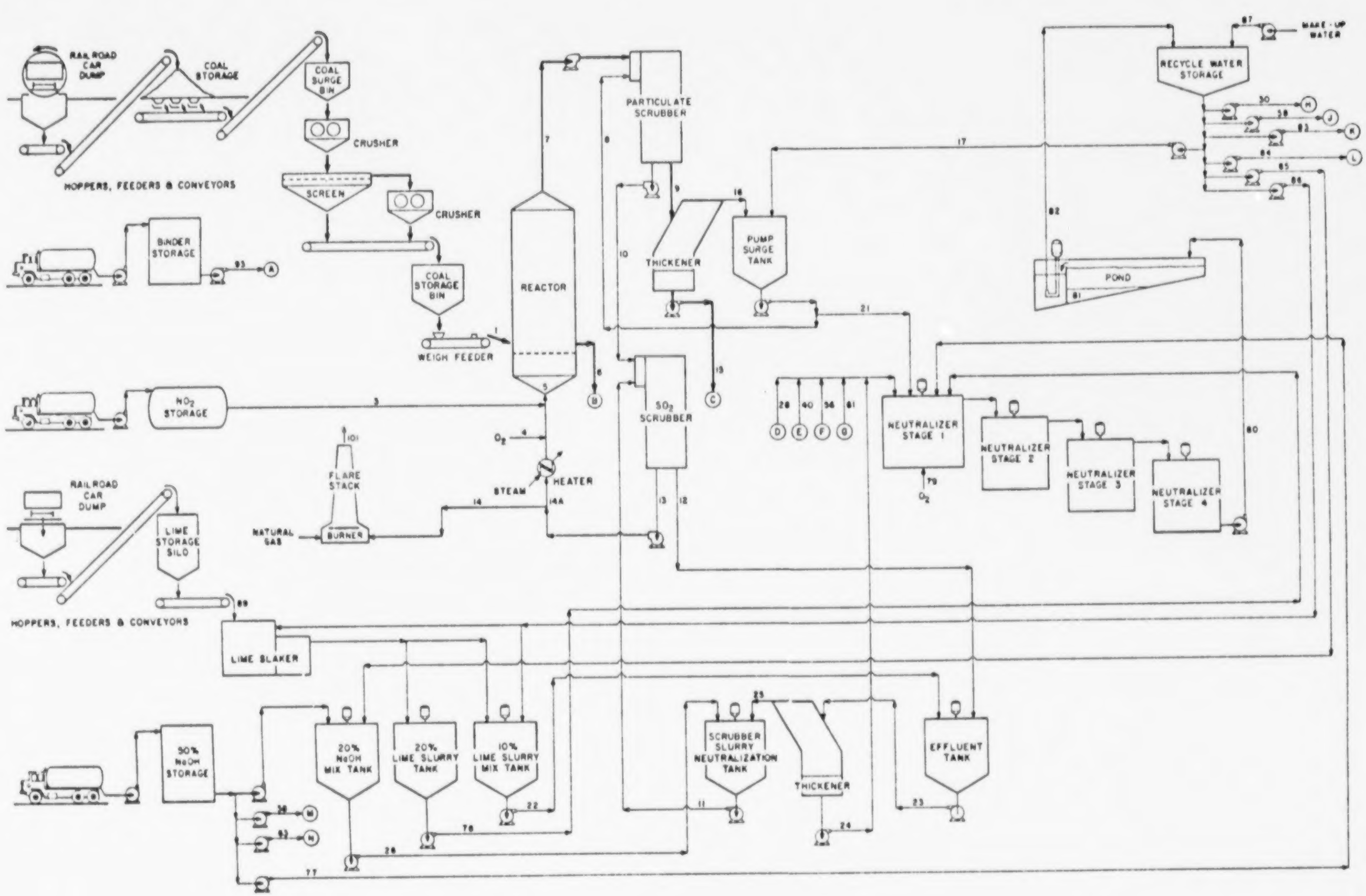

RAILROAD CAR DUMP
COAL STORAGE
COAL SURGE BIN
CRUSHER
SCREEN
CRUSHER
HOPPERS, FEEDERS & CONVEYORS
BINDER STORAGE
93
A
COAL STORAGE BIN
WEIGH FEEDER
1
REACTOR
7
5
6
B
NO2 STORAGE
3
O2
4
HEATER
STEAM
14A
14
FLARE STACK
101
NATURAL GAS
BURNER
PARTICULATE SCRUBBER
8
9
10
THICKENER
16
PUMP SURGE TANK
15
C
SO2 SCRUBBER
13
12
21
17
28
40
56
61
D
E
F
G
NEUTRALIZER STAGE 1
79
O2
NEUTRALIZER STAGE 2
NEUTRALIZER STAGE 3
NEUTRALIZER STAGE 4
80
RECYCLE WATER STORAGE
87
MAKE-UP WATER
30
H
38
J
83
K
84
L
85
86
82
POND
81
RAILROAD CAR DUMP
LIME STORAGE SILO
HOPPERS, FEEDERS & CONVEYORS
89
LIME SLAKER
50% NaOH STORAGE
36
M
92
N
77
20% NaOH MIX TANK
26
20% LIME SLURRY TANK
78
10% LIME SLURRY MIX TANK
22
SCRUBBER SLURRY NEUTRALIZATION TANK
11
25
THICKENER
24
EFFLUENT TANK
23

Figure 7. Flow diagram for KVB CCC process.

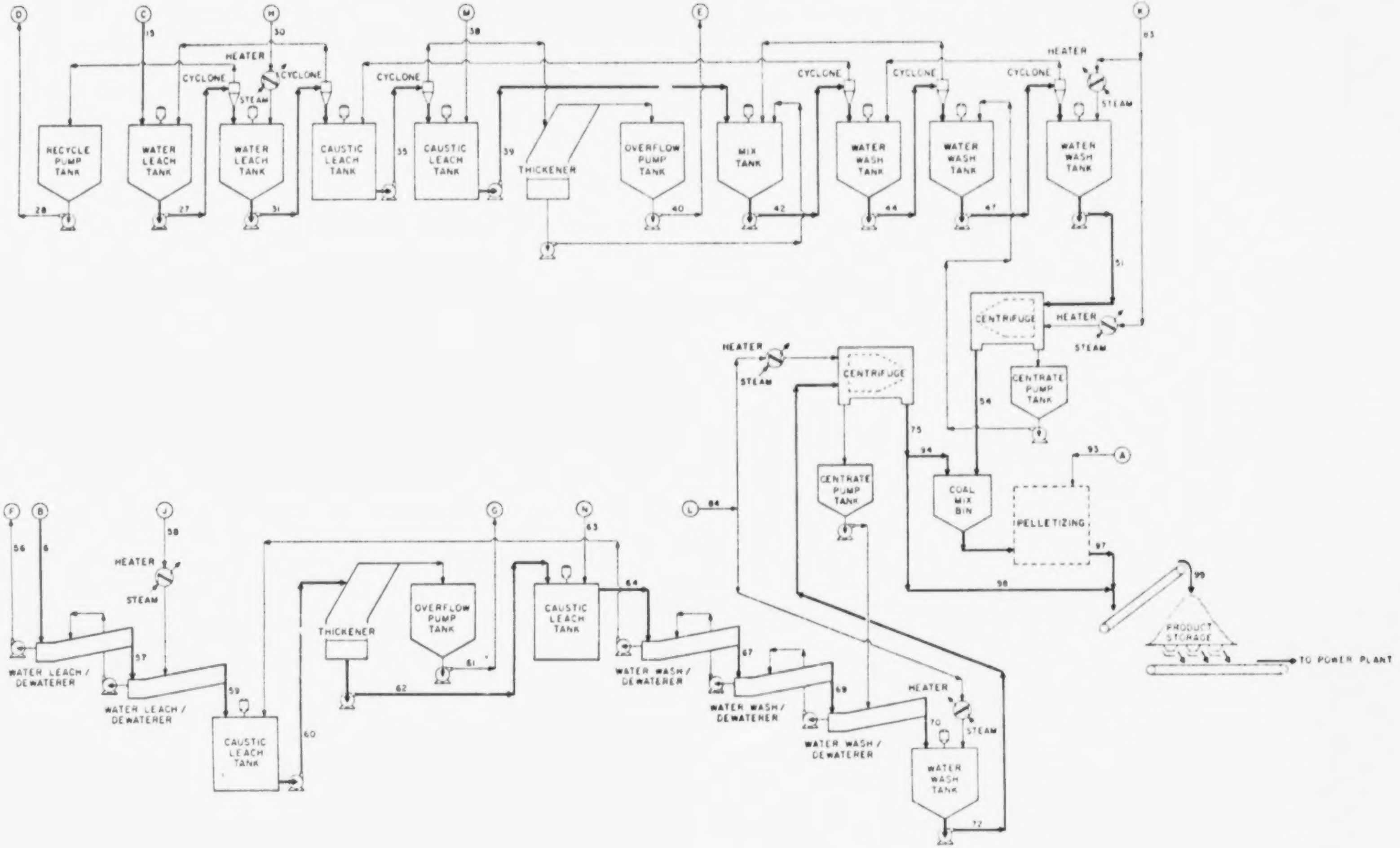

D
C
M
M
E
K
15
30
38
83
HEATER
CYCLONE
STEAM
RECYCLE PUMP TANK
WATER LEACH TANK
WATER LEACH TANK
CAUSTIC LEACH TANK
CAUSTIC LEACH TANK
THICKENER
OVERFLOW PUMP TANK
MIX TANK
WATER WASH TANK
WATER WASH TANK
WATER WASH TANK
28
27
31
35
39
40
42
44
47
51
CENTRIFUGE
CENTRATE PUMP TANK
54
94
75
93
A
COAL MIX BIN
PELLETIZING
97
98
99
PRODUCT STORAGE
TO POWER PLANT
F
B
J
G
N
L
56
6
58
63
84
WATER LEACH / DEWATERER
WATER LEACH / DEWATERER
57
59
CAUSTIC LEACH TANK
60
THICKENER
OVERFLOW PUMP TANK
61
62
CAUSTIC LEACH TANK
64
WATER WASH / DEWATERER
67
WATER WASH / DEWATERER
69
WATER WASH / DEWATERER
70
WATER WASH TANK
72

Figure 7. Flow diagram for KVB CCC process (continued).

The SO_2 is removed from the oxidizing gas stream by scrubbing with Na_2SO_3. The scrubbing reaction is:

$$SO_2 + Na_2SO_3 + H_2O \rightarrow 2NaHSO_3$$

The sodium-bisulfite solution is treated with slaked lime to regenerate Na_2SO_3 and produce a calcium sulfite sludge.

$$2NaHSO_3 + Ca(OH)_2 \rightarrow CaSO_3 + Na_2SO_3 + H_2O$$

This sludge is further treated with O_2 in the neutralizer to produce $CaSO_4$ and Na_2SO_4.

The hot water wash and leaching solutions are also treated in the neutralizer with slaked lime. The neutralizer reactions produce a waste sludge of gypsum and sodium jarosite. The neutralizer reactions consist of:

$$CaSO_3 + Na_2SO_3 + O_2 \rightarrow CaSO_4 + Na_2SO_4$$

$$Na_2SO_4 + Ca(OH)_2 \rightarrow 2NaOH + CaSO_4$$

$$3NaOH + 2FeSO_4 + Fe(OH_3) \rightarrow Na_3Fe_3(SO_4)_2(OH)_6$$

The principal problems in the process are the potential explosion hazards involved in the dry oxidation of pulverized coal, obtaining efficient scrubbing of coal dust and SO_2 from the oxidizing gas stream, energy consumed in preheating the oxidizing gas stream, possible nitrogen uptake in the coal, the large amount of agglomerating equipment required, and potential environmental problems associated with the disposal of the gypsum-sodium jarosite sludge.

A conceptual process using 5% sulfur coal sufficient to supply a 2000-MW power plant is described below.

Coal of 3-inch top size is transferred from the open-air stockpile to two parallel surge bins. The coal is reduced to 1-1/2-inch top size in two parallel double-roll crushers and screened to remove all 1/8 inch x 0 material on two parallel vibrating screen decks. The oversize material is further reduced in two additional double-roll crushers to 1/4-inch top size and then combined with the screened material. The combined materials, containing 35% 28 mesh x 0 fines, are stored in four parallel reactor feed bins.

The crushed coal is fed to the four fluidized-bed reactors at a total rate of 593 tons/hr. Hot oxidizing gas, containing 5% NO_2, 2.5% O_2, N_2, H_2O, and a trace of SO_2, contacts the coal in the reactor and selectively oxidizes about 98% of the pyritic sulfur and about 30% of the organic sulfur to sulfates and SO_2 gas. These reactions occur at 200°F and atmospheric pressure. The reactions are exothermic but do not supply enough heat to maintain the reactor at the required temperature.

The 28 mesh x 0 fine coal is entrained by the oxidizing gas stream and removed from the reactors in the off-gas stream. The 1/4 inch x 28 mesh coarse coal is removed from the bottom of the reactors and transferred to four parallel coarse coal washing and leaching trains.

The reactor off-gas containing the fine coal and SO_2 is scrubbed with water to remove the fine coal in four parallel venturi particulate scrubbers. The off-gas then passes through four parallel venturi scrubbers where most of the SO_2 is removed by a dilute solution of Na_2SO_3. The cleaned gas is heated to 302°F in four parallel preheaters using power plant steam. The heated gas, along with makeup O_2 and NO_2, is recycled to the fluidized-bed reactors.

A small amount of the cleaned gas stream is removed before heating to prevent the buildup of CO_2, N_2, SO_2, and NO_x compounds in the oxidizing gas. The portion removed from all four trains is processed in a two-stage combustion "scrubber" where NO_x compounds are converted to N_2 by contact with natural gas.

The reacted solution from the SO_2 absorbers is treated with slaked lime to produce $CaSO_3$ and to regenerate Na_2SO_3. The resulting slurry is increased to 15% solids in four parallel thickeners and then transferred to the leach solution neutralization area. The thickener overflow, with makeup NaOH, is recycled to the SO_2 absorbers.

The fine coal slurry from the particulate scrubbers, containing some HCl and H_2SO_4, is increased to 37% solids in four parallel thickeners, then transferred to four fine-coal washing and leaching trains. The thickener overflow solution flows to surge tanks from which a bleedstream is transferred to the leach solution neutralization area to prevent the buildup of HCl and H_2SO_4 in the scrubber loops. The remainder of the solution, with makeup water, is recycled to the particulate scrubbers.

The fine coal is leached countercurrently with 200°F water in four parallel systems with two stages of leach tanks and cyclone classifiers which remove about 95% of the $FeSO_4$ in the coal. The water-leached coal is then leached countercurrently with 200°F NaOH solution in four parallel systems with two stages of wash tanks and cyclone classifiers, which remove the remaining $FeSO_4$ and converts the oxidized organic sulfur to soluble Na_2SO_4. The caustic-leached coal is then washed countercurrently with 200°F water in four parallel systems with three stages of wash tanks and cyclone classifiers, followed by fourth-stage water-wash centrifuges which dewater the cleaned coal to about 10% moisture. The spent water and NaOH solutions are transferred to the leach solution neutralization area.

The coarse coal from the fluidized-bed reactors is processed by the same method used in the fine coal washing and leaching area except spiral classifiers are used in place of tanks and cyclones.

The combined liquors from the particulate scrubbers, SO_2 absorbers, fine coal leaching, and coarse coal leaching are treated with NaOH solution, slaked lime, and sparged O_2 to produce $CaSO_4 \cdot 2H_2O$ (gypsum) and sodium jarosite. The neutralized slurry of gypsum and jarosite is pumped to a settling pond, from which supernate water is returned to a recycle water tank for use in the process.

All of the fine coal product and 15% of the coarse coal product are pelletized in 11 parallel pelletizing systems. The pelletized coal, containing 5% moisture, is combined with the nonpelletized portion and stored in open-air stockpiles. The product contains 1.32 wt % sulfur and 13.7% ash. This process reduces the total sulfur by 76% and the total ash by 18%.

Cleaning Performance and Base-Case Costs

The cleaning performance of the KVB process is shown in Table 9 for the four premise coals. It is compared with that of other processes in the Results section.

TRW GRAVICHEM CHEMICAL COAL-CLEANING PROCESS

The flow diagram is shown in Figure 8. The base-case material balance and equipment list are located in Appendix A.

Process Description

This process is the result of several years of research and development in chemical desulfurization of coal by TRW (Hamersma, et al., 1974, 1975; Koutsoukos, et al., 1976a, 1976b; Meyers, 1977). The developer claims the process will remove 95% to 99% of the pyritic sulfur but none of the organic sulfur. The leaching - regeneration and subsequent washing and filtration have been demonstrated in an 8-ton-per-day process test plant at TRW's Capistrano Test Site in California in late 1977. The sink-float gravity separation, the solvent extraction of sulfur, and the solvent recovery steps remain to be demonstrated on a pilot-plant scale. The process development is presently inactive because of lack of financial support.

The process consists of a sink-float gravity separation, followed by selective oxidation with ferric sulfate and subsequent leaching. The oxidation reaction consists of:

$$FeS_2 + 4.6Fe_2(SO_4)_3 + 4.8H_2O \rightarrow 10.2FeSO_4 + 4.8H_2SO_4 + 0.8S$$

The $Fe_2(SO_4)_3$ solution is regenerated by sparging with O_2 which can be done either concurrently with the pyritic sulfur leaching reaction or as a separate process step. The regeneration reaction consists of:

$$9.6FeSO_4 + 4.8H_2SO_4 + 2.4O_2 \rightarrow 4.8Fe_2(SO_4)_3 + 4.8H_2O$$

TABLE 9. CLEANING PERFORMANCE OF KVB PROCESS

(MOISTURE-FREE BASIS)

	0.7% sulfur coal		2.0% sulfur coal		3.5% sulfur coal		5.0% sulfur coal	
	Raw coal	Product	Raw coal	Product	Raw coal	Product	Raw coal	Product
Total sulfur, %	0.70	0.37	2.00	0.53	3.50	1.00	5.00	1.32
Pyritic sulfur, %	0.24	0.01	1.32	0.03	2.22	0.05	3.35	0.07
Organic sulfur, %	0.45	0.32	0.64	0.46	1.23	0.91	1.59	1.21
Sulfate sulfur, %	0.01	0.04	0.04	0.04	0.05	0.04	0.06	0.04
Ash, %	11.5	11.2	14.5	13.3	14.0	11.9	16.7	13.7
Btu/lb	11,700	11,800	13,000	13,400	12,700	13.300	12,000	12,900
Btu recovery, %	-	99.9	-	99.5	-	99.2	-	98.8
Weight recovery, %	-	99.4	-	96.9	-	94.7	-	92.12
Total sulfur, lb/MBtu	0.60	0.31	1.54	0.40	2.76	0.75	4.17	1.02
Sulfur removal, % Btu basis	-	48	-	74	-	73	-	76

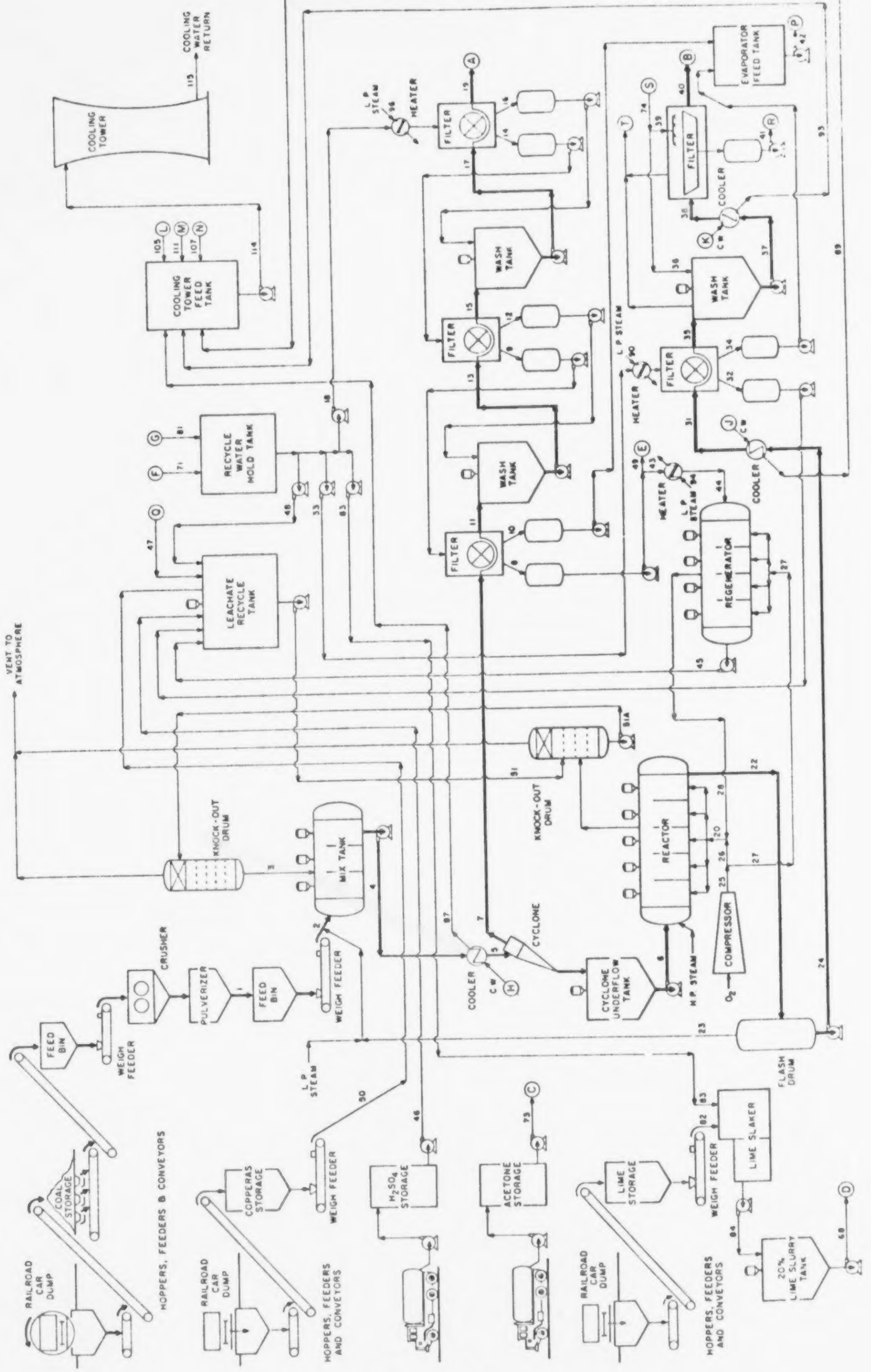
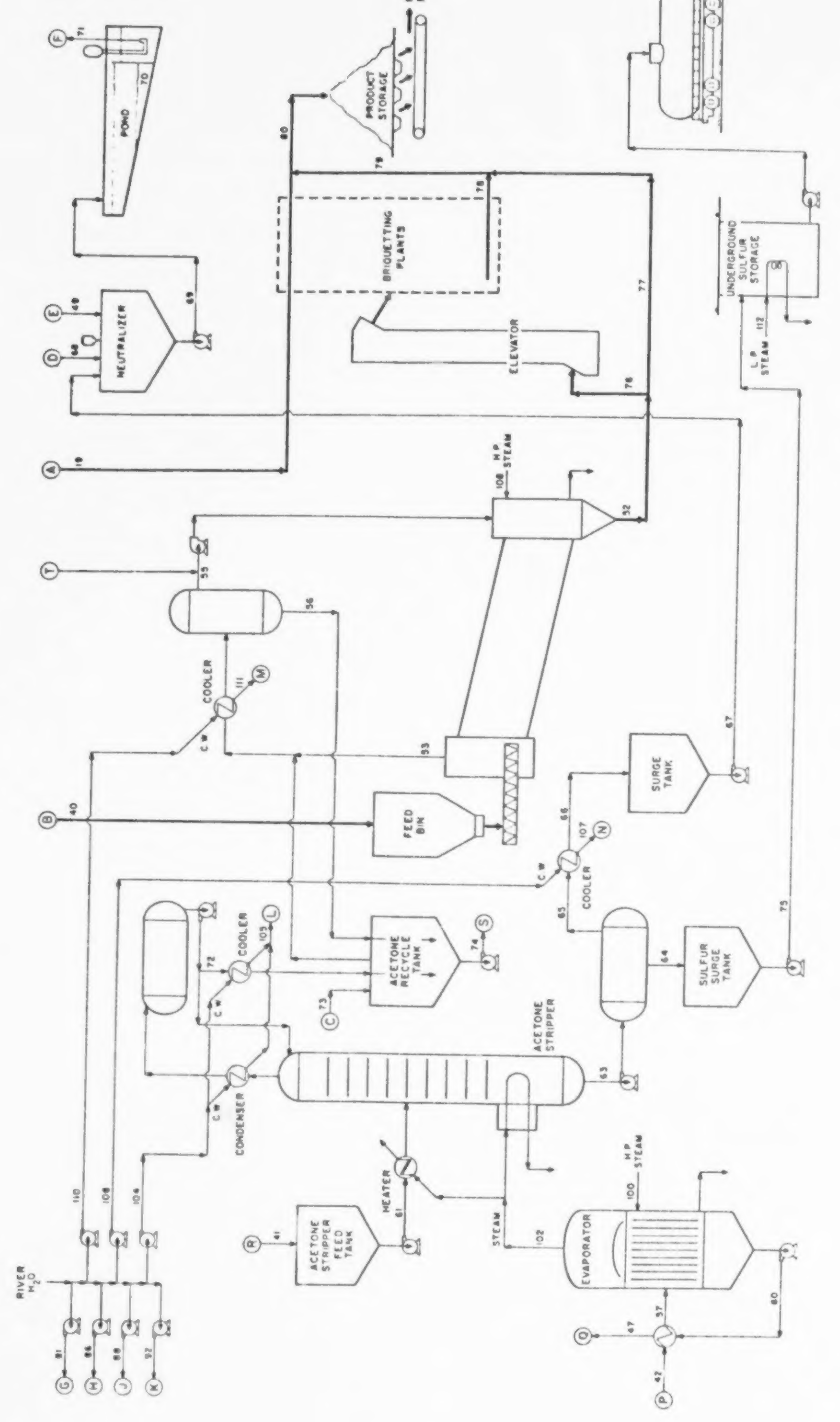

RAILROAD CAR DUMP
COAL STORAGE
HOPPERS, FEEDERS & CONVEYORS
FEED BIN
WEIGH FEEDER
CRUSHER
PULVERIZER
FEED BIN
WEIGH FEEDER
MIX TANK
KNOCK-OUT DRUM
VENT TO ATMOSPHERE
LEACHATE RECYCLE TANK
RECYCLE WATER HOLD TANK
COOLING TOWER FEED TANK
COOLING TOWER
COOLING WATER RETURN
FILTER
WASH TANK
HEATER
L.P. STEAM
EVAPORATOR FEED TANK
COOLER
C.W.
REGENERATOR
REACTOR
COMPRESSOR
O_2
H.P. STEAM
CYCLONE
CYCLONE UNDERFLOW TANK
FLASH DRUM
RAILROAD CAR DUMP
COPPERAS STORAGE
HOPPERS, FEEDERS AND CONVEYORS
WEIGH FEEDER
H_2SO_4 STORAGE
ACETONE STORAGE
RAILROAD CAR DUMP
LIME STORAGE
HOPPERS, FEEDERS AND CONVEYORS
WEIGH FEEDER
LIME SLAKER
20% LIME SLURRY TANK

Figure 8. Flow diagram for TRW Gravichem CCC process.



A
18
B
40
T
55
POND
70
71
F
NEUTRALIZER
D
68
E
49
69
PRODUCT STORAGE
TO POWER PLANT
80
79
78
BRIQUETTING PLANTS
ELEVATOR
76
77
UNDERGROUND SULFUR STORAGE
L.P. STEAM
112
H.P. STEAM
108
52
56
COOLER
111
M
C.W.
53
FEED BIN
SURGE TANK
67
66
107
N
COOLER
65
ACETONE RECYCLE TANK
74
S
73
C
72
COOLER
105
L
SULFUR SURGE TANK
64
75
ACETONE STRIPPER
63
CONDENSER
HEATER
61
ACETONE STRIPPER FEED TANK
R
41
STEAM
102
EVAPORATOR
H.P. STEAM
100
RIVER H₂O
110
106
104
G
81
H
86
J
88
K
92
Q
47
57
P
42
60

Figure 8. Flow diagram for TRW Gravichem CCC process (continued).

Combining the two reactions gives an overall process reaction which consists of:

$$FeS_2 + 2.4O_2 \rightarrow 0.6FeSO_4 + 0.2Fe_2(SO_4)_3 + 0.8S$$

The leaching and regeneration reactions are both exothermic but do not supply enough heat to maintain the reactor temperature.

The spent leaching solution is neutralized with slaked lime to produce a waste sludge of gypsum and iron hydroxides.

$$FeSO_4 + Ca(OH)_2 \rightarrow CaSO_4 + Fe(OH)_2$$

$$Fe_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 3CaSO_4 + 2Fe(OH)_3$$

$$H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4 + 2H_2O$$

The principal problems in the process are the presence of a very corrosive dilute sulfuric acid-iron sulfate solution, high energy consumption due to the heat transfer requirements, high capital cost of the heat transfer equipment and the solvent recovery area, the large amount of agglomerating equipment required, and potential environmental problems associated with the disposal of the gypsum and iron hydroxide sludge.

A conceptual process using 5% sulfur coal sufficient to supply a 2000-MW power plant is described below.

Coal of 3-inch top size is transferred from the open-air storage area to a surge bin. The coal is reduced to 3/4-inch top size by two parallel crushers. It is further reduced to 14-mesh top size by two parallel pulverizers and stored in four 2-hour surge bins.

The coal, at a total rate of 593 tons/hr, is preheated by low-pressure steam and fed to two parallel mixing tanks. The coal is slurried in the mixing tanks with 215°F recycled leach solution containing 7.5% total iron as $FeSO_4$ and $Fe_2(SO_4)_3$ plus 4% H_2SO_4.

The slurried coal, containing 25% solids, is cooled in 13 parallel heat exchangers to control the specific gravity of the leachate in the slurry at 1.31. Since the leach solution is a true solution and not a dispersion of finely ground magnetite commonly used in heavy media sink-float systems, the specific gravity of the leach solution will not change during the physical separation process. Because of this, the 1.31 specific gravity will approximate the separation results of the 1.30 specific gravity laboratory wash tests. Slurry from the coolers is pumped to 54 cyclones which make a continuous 1.30 specific gravity separation. The cyclone overflow, or "float" fraction, contains about 32% of the total coal and has a low pyrite concentration. The remainder of the coal goes to the cyclone underflow, or "sink" fraction, and contains coal with a high pyrite concentration.

The overflow fraction is filtered by three rotary drum filters to remove the iron sulfate-sulfuric acid solution and then washed in two stages with 160°F water. This reduces the sulfate salts to a level of 0.04% to 0.06% in the product coal. Each wash stage consists of a wash tank and three rotary drum filters which produce a filter cake containing about 33% moisture. A portion of the iron sulfate-sulfuric acid solution removed by the first filtration is bled to the neutralization area in order to remove the $FeSO_4$ and $Fe_2(SO_4)_3$ produced by the process reactions. The remainder of the iron sulfate-sulfuric acid solution is pumped through six parallel preheaters to the regenerator. A residence time of 30 minutes in the regenerator, which operates at 250°F and 35 psig, gives a required Y ratio (ferric iron/total iron) of 0.90 in the leach solution.

The wash water, containing $FeSO_4$ and $Fe_2(SO_4)_3$, removed from the first filtration is pumped to the evaporator system to be concentrated.

The underflow fraction is pumped to three parallel process reactors. These reactors operate at 250°F and 35 psig. The reactors are sized for a 6-hour residence time, which is required for pyrite to react with $Fe_2(SO_4)_3$. The leaching and regeneration reactions are both exothermic but do not supply enough heat to maintain the reactor at 250°F. To maintain the proper temperature in the reactor, high-pressure steam is sparged into the bottom of the reactor. The reacted slurry flows to three parallel flash drums, where low-pressure flash steam is produced at 2 to 3 psig and 219°F. The slurry, at 219°F, is then pumped to eight parallel slurry coolers where it is cooled to 160°F. The coal slurry is then filtered and washed with 160°F water in five rotary drum filters. The strong leach solution from the filter is pumped to the leachate recycle tank and the wash water is pumped to the evaporator system to be concentrated.

The filtered coal, containing about 33% moisture, is slurried with acetone in five parallel mix tanks and cooled to 85°F in 27 heat exchangers. The coal-acetone slurry is then filtered in 12 parallel horizontal rotary pan filters where the cake is washed with additional acetone. This acetone leaching of the coal reduces the elemental sulfur in the coal to 0.2% and the sulfate sulfur to 0.02%. The acetone removed by the filter is pumped to the acetone reclaim stripper and the coal, containing about 33% acetone, is conveyed to the drying systems.

The coal is dried in 12 parallel rotary steam tube dryers at 133°F where the acetone in the coal is evaporated. The acetone is removed by 12 ID fans, condensed, and sent to the acetone recycle tank. Eighty percent of the dried coal product, containing 14% water, is hot briquetted. The briquetted coal is combined with the remainder of the dried coal on the product conveyor. This material is then combined with the float coal product and conveyed to an open-air stockpile.

The acetone from the filters, containing water, sulfates, and elemental sulfur, is pumped to the acetone stripper. The stripper, operating at 15 psig and 250°F removes the acetone from the water, sulfates, and sulfur. The acetone is sent to the acetone recycle tank. The water, sulfates, and sulfur are removed from the bottom of the stripper and sent to a surge tank. Here the sulfur is removed in the liquid state and pumped to storage. The water and sulfates are cooled to 160°F and pumped to the neutralization area.

The wash water from the filtration and wash area, containing iron sulfates, is pumped through a preheater to a long-tube, natural-circulation evaporator operating at 35 psig and 290°F. The evaporator bottoms are pumped through the feed preheater to the leachate recycle tank. The bottoms are concentrated such that the total leach solution being fed to the mix tanks contains 7.5% total iron as $FeSO_4$ and $Fe_2(SO_4)_3$ with a Y ratio of 0.90.

The bleedstream from the strong leachate and the bottoms from the stripper are neutralized using slaked lime to produce $CaSO_4 \cdot 2H_2O$, $Fe(OH)_2$, and $Fe(OH)_3$. The neutralized slurry is pumped to a settling pond. Supernate water is reclaimed from the settling pond and pumped back to the cleaning plant recycle water tank.

The clean coal product produced by this process has a total sulfur content of 1.9 wt % and ash content of 13.6% on a moisture-free basis. This is a reduction of 64% in the total sulfur and 19% in the total ash. The ash reduction is obtained by the removal of iron as a result of the pyritic reaction producing iron sulfates which are bled to the neutralizer and then to the settling pond.

Cleaning Performance and Base-Case Costs

The cleaning performance of the TRW process is shown in Table 10 for the four premise coals. It is compared with that of other processes in the Results section.

KENNECOTT CHEMICAL COAL-CLEANING PROCESS

The flow diagram is shown in Figure 9. The base-case material balance and equipment list are located in Appendix A.

Process Description

Kennecott Copper Corporation began development of this process in 1970 as part of a program to maintain markets for the high-sulfur coal production and reserves of its wholly owned subsidiary, Peabody Coal Company (Agarwal et al., 1978; Jackson, 1977). The development continued through May 1975 and was demonstrated at bench scale. Development was stopped when the U.S. Supreme Court validated the FTC order to Kennecott for divestiture of Peabody Coal.

The process consists of an oxygen-oxidation system in which a portion of the sulfur in the coal is oxidized to soluble sulfates by

TABLE 10. CLEANING PERFORMANCE OF TRW GRAVICHEM PROCESS

(MOISTURE-FREE BASIS)

	0.7% sulfur coal		2.0% sulfur coal		3.5% sulfur coal		5.0% sulfur coal	
	Raw coal	Product	Raw coal	Product	Raw coal	Product	Raw coal	Product
Total sulfur, %	0.7	0.50	2.0	0.78	3.50	1.47	5.00	1.95
Pyritic sulfur, %	0.24	0.005	1.32	0.03	2.22	0.05	3.35	0.07
Organic sulfur, %	0.45	0.45	0.64	0.66	1.23	1.29	1.59	1.70
Sulfate sulfur, %	0.01	0.04	0.04	0.04	0.05	0.04	0.06	0.04
Elemental sulfur, %	0	0.009	0	0.05	0	0.09	0	0.14
Ash, %	11.5	11.3	14.5	13.4	14.0	11.9	16.7	13.6
Btu/lb	11,700	11,700	13,000	13,300	12,700	13,300	12,000	12,900
Btu recovery, %	-	99.5	-	99.6	-	99.3	-	98.9
Weight recovery, %	-	99.5	-	97.3	-	95.2	-	92.8
Total sulfur, lb/MBtu	0.60	0.43	1.54	0.59	2.76	1.11	4.17	1.51
Sulfur removal, % Btu basis	-	28	-	62	-	60	-	64

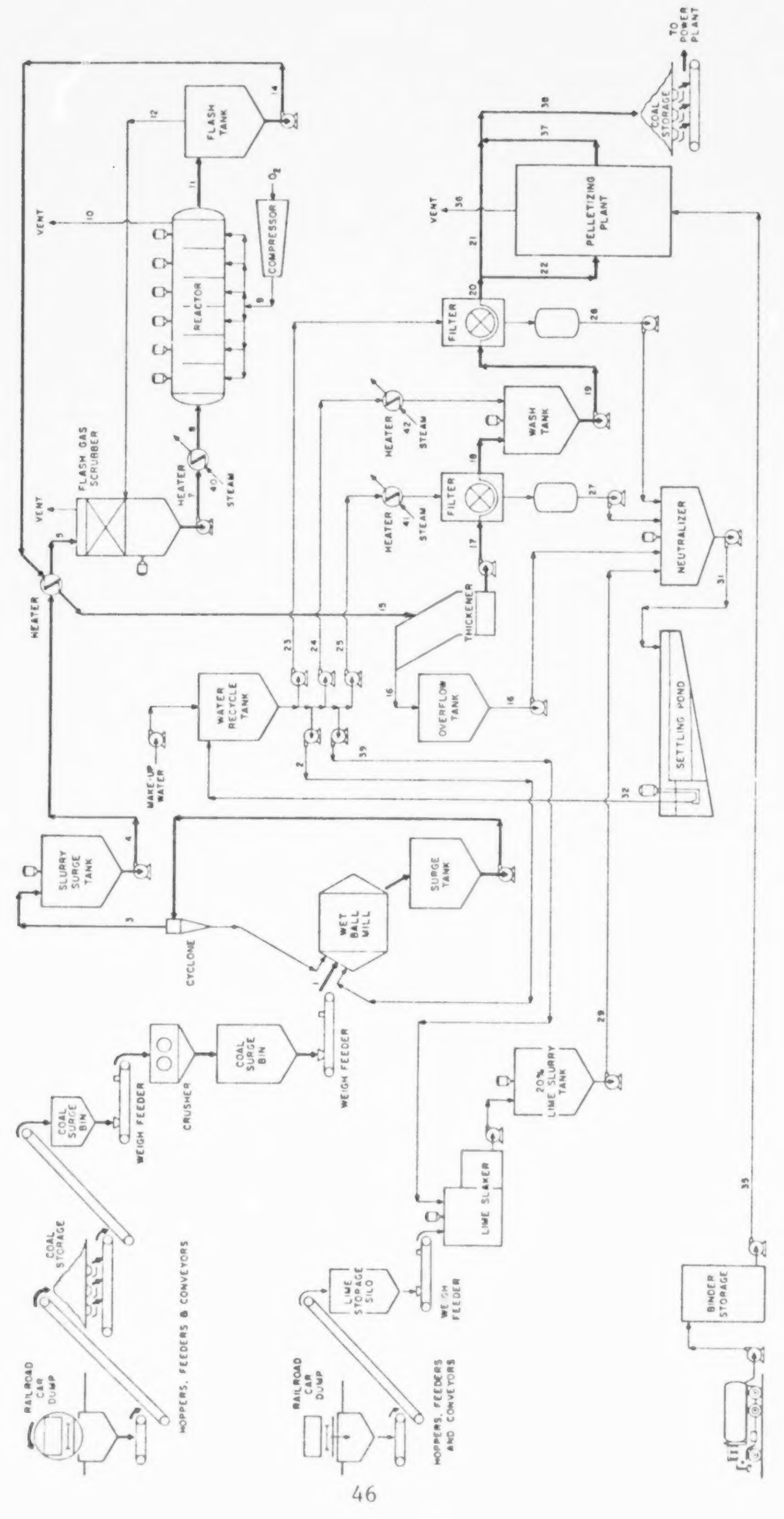

RAILROAD CAR DUMP
HOPPERS, FEEDERS & CONVEYORS
COAL STORAGE
COAL SURGE BIN
WEIGH FEEDER
CRUSHER
COAL SURGE BIN
WEIGH FEEDER
WET BALL MILL
SURGE TANK
CYCLONE
SLURRY SURGE TANK
HEATER
VENT
FLASH GAS SCRUBBER
HEATER
STEAM
REACTOR
COMPRESSOR
O2
VENT
FLASH TANK
MAKE-UP WATER
WATER RECYCLE TANK
THICKENER
OVERFLOW TANK
HEATER
STEAM
FILTER
HEATER
STEAM
WASH TANK
FILTER
VENT
PELLETIZING PLANT
COAL STORAGE
TO POWER PLANT
NEUTRALIZER
SETTLING POND
RAILROAD CAR DUMP
HOPPERS, FEEDERS AND CONVEYORS
LIME STORAGE SILO
WEIGH FEEDER
LIME SLAKER
20% LIME SLURRY TANK
BINDER STORAGE
1
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Figure 9. Flow diagram for Kennecott CCC process.

sparging O_2 through pulverized coal under heat and pressure. The organic sulfur reaction is not fully understood. The pyritic sulfur reaction consists of:

$$FeS_2 + 3.69O_2 + 1.75H_2O \rightarrow 0.25FeSO_4 + 0.38Fe_2O_3 + 1.75H_2SO_4$$

The reaction is exothermic and provides sufficient heat to maintain the reaction temperature. The soluble sulfates are removed by washing and neutralized with slaked lime to produce a waste sludge of iron hydroxide and gypsum:

$$0.25FeSO_4 + 1.75H_2SO_4 + 2Ca(OH)_2 \rightarrow 0.25Fe(OH)_2 + 2CaSO_4 + 3.5H_2O$$

The principal problems in this process are the presence of a very corrosive dilute sulfuric acid and $FeSO_4$ solution, reactor design limitations due to high operating pressures, large amount of agglomerating equipment required, and potential environmental problems associated with the disposal of the gypsum-iron hydroxide sludge.

A conceptual process using 5% sulfur coal sufficient to supply a 2000-MW power plant is described below.

Coal of 3-inch top size containing 5% sulfur is transferred from the open-air stockpile to an 8-hour-capacity crusher feed bin. The coal is reduced to 3/4-inch top size in two parallel double-roll crushers and stored in two 4-hour-capacity surge bins which feed two parallel wet ball mill systems.

The crushed coal is fed to the ball mills at a total rate of 680 tons/hr. The ball mills, using recycled water from the settling pond, pulverize the coal to 80% 100 mesh x 0. Slurry from the ball mills is passed through eight parallel cyclone separators which return oversized material to the ball mills. The cyclone separator overflow, containing 23% solids, is heated to about 150°F in six parallel reclaim heat exchangers using reacted slurry from the reactors. The heated slurry is pumped through three parallel scrubbers, operating at 15 psig, where it is further heated to about 250°F by steam from the reactor flash tanks. The slurry is then heated to 350°F in five parallel preheaters using power plant steam.

The heated slurry is then passed through three parallel trains of 10 reactors each. Each reactor has six agitated stages with provision for sparging with compressed O_2. The reactor trains operate at 350°F and 315 psig; they are designed for a 1-hour hold time, necessary to convert 88% of pyritic sulfur and some of the organic sulfur to sulfate. The heat of reaction is sufficient to maintain the system at 350°F.

The reacted slurry is flashed in three parallel flash tanks which reduce the slurry temperature to 250°F and produce 15 psig saturated steam for the scrubbers. The slurry is passed through the reclaim heat exchangers, where it is cooled to about 165°F, and then increased to 35% solids in six parallel thickeners.

The thickened coal is washed with 165°F recycle water in nine parallel rotary drum filters to remove most of the $FeSO_4$ and H_2SO_4. It is then reslurried in three parallel coal wash tanks using 165°F recycle water and washed with unheated, recycle water in an additional nine rotary drum filters to remove most of the remaining $FeSO_4$ and H_2SO_4.

The clear liquid from the thickeners and filters containing $FeSO_4$ and H_2SO_4 is pumped from overflow tanks to a neutralizer where it is neutralized with slaked lime. The neutralized slurry of gypsum and iron hydroxide is pumped to a settling pond, from which supernate water is returned to a recycle water tank for use in the process.

Eighty percent of the washed coal, containing 35% water, is pelletized in 33 parallel pelletizing systems. The pelletized coal, containing 5% moisture, is combined with the unpelletized portion and stored in open-air stockpiles. The product coal contains 1.8 wt % sulfur, 63.2 wt % carbon, and 12.3 wt % oxygen on a moisture-free basis. The process reduces the sulfur by 62% and carbon by 2.9%, and increases the oxygen by 5.8%.

Cleaning Performance and Base-Case Costs

The cleaning performance of the Kennecott process is shown in Table 11 for the four premise coals. It is compared with that of other processes in the Results section.

TABLE 11. CLEANING PERFORMANCE OF KENNECOTT PROCESS

(MOISTURE-FREE BASIS)

	0.7% sulfur coal		2.0% sulfur coal		3.5% sulfur coal		5.0% sulfur coal	
	Raw coal	Product	Raw coal	Product	Raw coal	Product	Raw coal	Product
Total sulfur, %	0.70	0.45	2.0	0.73	3.50	1.34	5.0	1.81
Pyritic sulfur, %	0.24	0.03	1.32	0.15	2.22	0.26	3.35	0.40
Organic sulfur, %	0.45	0.38	0.64	0.54	1.23	1.04	1.59	1.37
Sulfate sulfur, %	0.01	0.04	0.04	0.04	0.05	0.04	0.06	0.04
Ash, %	11.5	11.1	14.5	13.8	14.0	13.2	16.7	15.8
Btu/lb	11,700	10,800	13,000	12,100	12,700	11,900	12,000	11,300
Btu recovery, %	-	94.9	-	95.2	-	94.8	-	94.1
Weight recovery, %	-	102.8	-	102.6	-	101.5	-	100.1
Total sulfur, lb/MBtu	0.60	0.42	1.54	0.60	2.76	1.13	4.17	1.60
Sulfur removal, % Btu basis	-	30	-	61	-	59	-	62

COMBINATION COAL CLEANING

PCC I-KVB COMBINATION PROCESS

Process Description

This process combines the PCC I process using DM vessels, DM cyclones, and froth flotation with the KVB desulfurization process. The base-case flow diagram is shown in Figure 10. The base-case material balance and the equipment list are located in Appendix A. Coal of 3-inch top size is transferred from the open-air stockpile to the coal sizing area at the total rate of 840 tons/hr. Here the coal is crushed and screened to three size fractions for cleaning in the coarse, intermediate, and fine coal areas of the PCC I process. Since the PCC I process section of the plant has an on-stream operating time of 6000 hr/yr and the KVB process has an on-stream operating time of 8000 hr/yr, intermediate storage is needed to cover the 2-day weekend period when the physical cleaning plant is shut down for maintenance. Four silos provide this storage. The coal is then processed through the KVB section of the cleaning plant.

Cleaning Performance and Base-Case Costs

Table 12 shows the sulfur removal performance of the combination PCC I-KVB process. On a Btu basis, it is 52% for the subbituminous coal with 0.7% sulfur and 75%-78% for the bituminous coals.

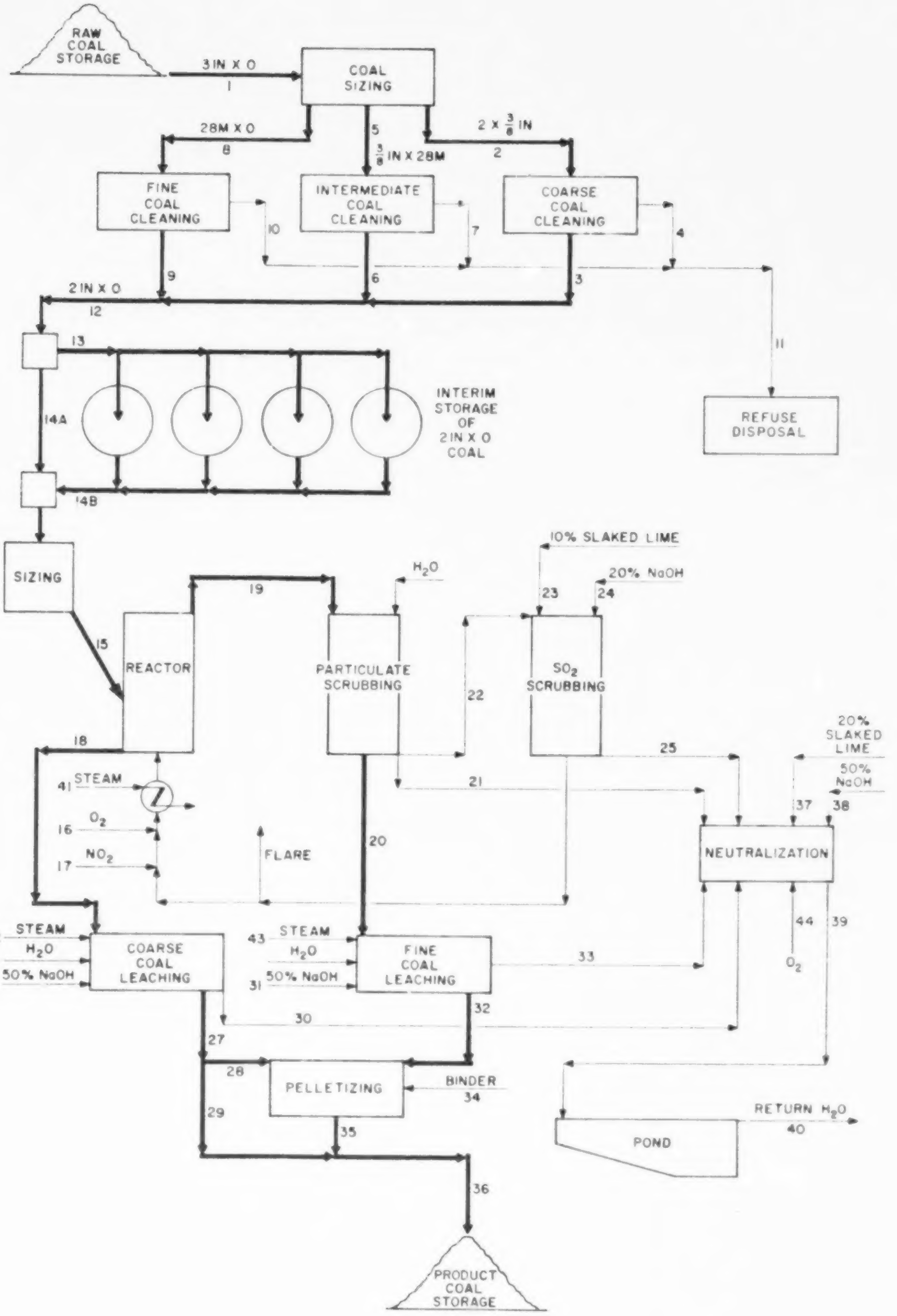
RAW COAL STORAGE
3 IN X 0
1
COAL SIZING
28M X 0
8
5
$\frac{3}{8}$ IN X 28M
2 X $\frac{3}{8}$ IN
2
FINE COAL CLEANING
INTERMEDIATE COAL CLEANING
COARSE COAL CLEANING
10
7
4
9
6
3
2 IN X 0
12
13
11
14A
INTERIM STORAGE OF 2 IN X 0 COAL
REFUSE DISPOSAL
14B
SIZING
10% SLAKED LIME
H_2O
20% NaOH
19
23
24
15
REACTOR
PARTICULATE SCRUBBING
22
SO_2 SCRUBBING
18
25
20% SLAKED LIME
50% NaOH
41 STEAM
21
37
38
16 O_2
17 NO_2
FLARE
20
NEUTRALIZATION
42 STEAM
H_2O
26 50% NaOH
COARSE COAL LEACHING
43 STEAM
H_2O
31 50% NaOH
FINE COAL LEACHING
33
44
39
O_2
30
32
27
28
PELLETIZING
BINDER
34
29
35
RETURN H_2O
40
POND
36
PRODUCT COAL STORAGE

Figure 10. Flow diagram for PCC I-KVB combination coal-cleaning process.

TABLE 12. CLEANING PERFORMANCE OF COMBINATION PCC-KVB PROCESSES

(MOISTURE-FREE BASIS)

	0.7% sulfur coal		2.0% sulfur coal		3.5% sulfur coal		5.0% sulfur coal	
	Raw coal	Product	Raw coal	Product	Raw coal	Product	Raw coal	Product
Total sulfur, %	0.70	0.36	2.00	0.53	3.50	0.98	5.00	1.26
Pyritic sulfur, %	0.24	0.003	1.32	0.02	2.22	0.03	3.35	0.04
Organic sulfur, %	0.45	0.32	0.64	0.47	1.23	0.91	1.59	1.18
Sulfate sulfur, %	0.01	0.04	0.04	0.04	0.05	0.04	0.06	0.04
Ash, %	11.5	7.7	14.5	6.8	14.0	6.7	16.7	8.0
Btu/1b	11,700	12,300	13,000	14,200	12,700	14,100	12,000	13,600
Btu recovery, %	-	95.0	-	92.8	-	91.8	-	89.6
Weight recovery, %	-	90.7	-	84.5	-	82.6	-	80.1
Total sulfur, 1b/MBtu	0.60	0.29	1.54	0.37	2.76	0.70	4.17	0.93
Sulfur removal, % Btu basis	-	52	-	76	-	75	-	78

COAL CLEANING - FGD COMBINATIONS

PCC I-FGD, KVB-FGD, AND PCC I-KVB-FGD PROCESSES

Coals with a sulfur content about 0.7% can meet the 1.2 lb SO_2/MBtu emission level without cleaning or scrubbing. Depending on the coal to be cleaned and on the process selected, the cleaning performances indicate that PCC processes can allow the use of coals with 1.0% to 1.7% sulfur in the case of new power plants and to a higher level for existing power plants under higher SIP standards. The CCC processes have higher levels of sulfur removal and would permit the use of coals with sulfur levels of up to about 3% for the 1.2 lb SO_2/MBtu emission level. Above these sulfur levels, coal cleaning provides partial control and reduces the remaining sulfur removal needed by FGD or other subsequent sulfur removal processes. To meet 85% SO_2 removal for new utility plants, all of the coals studied would require additional sulfur removal after either physical or chemical coal cleaning.

This section deals with cleaning by physical (PCC I), chemical (KVB), or physical-chemical (PCC I-KVB) processes, each followed by additional sulfur removal by FGD at the power plant. The coal cleaning and FGD results then can be combined for sulfur removal. FGD without coal cleaning is included for comparison.

Process Description

Process and economic features of the coal-cleaning segments of the combination processes are the same as described earlier. Partial scrubbing by limestone FGD is tailored for each case variation of emission standard and sulfur content in the coal.

The basic FGD system is a conventional limestone slurry system, as shown in Figure 11. The FGD section begins with the plenum which is located downstream from the ESP and the ID fan. The ESP and ID fan costs are not included in the FGD costs. Each FGD train has a forced-draft (FD) fan to offset the pressure drop through the system. The SO_2 absorber is a countercurrent mobile-bed scrubber with a presaturator and an integral mist eliminator. The cleaned flue gas is reheated to 175°F by an indirect steam heated reheater. In the absorber, SO_2 is absorbed in a recirculating slurry of limestone to produce calcium sulfite and calcium sulfate solids. The slurry is maintained at 15% solids by the addition of makeup limestone slurry from a central preparation area and by the withdrawal of a purge stream which is pumped to a clay-lined

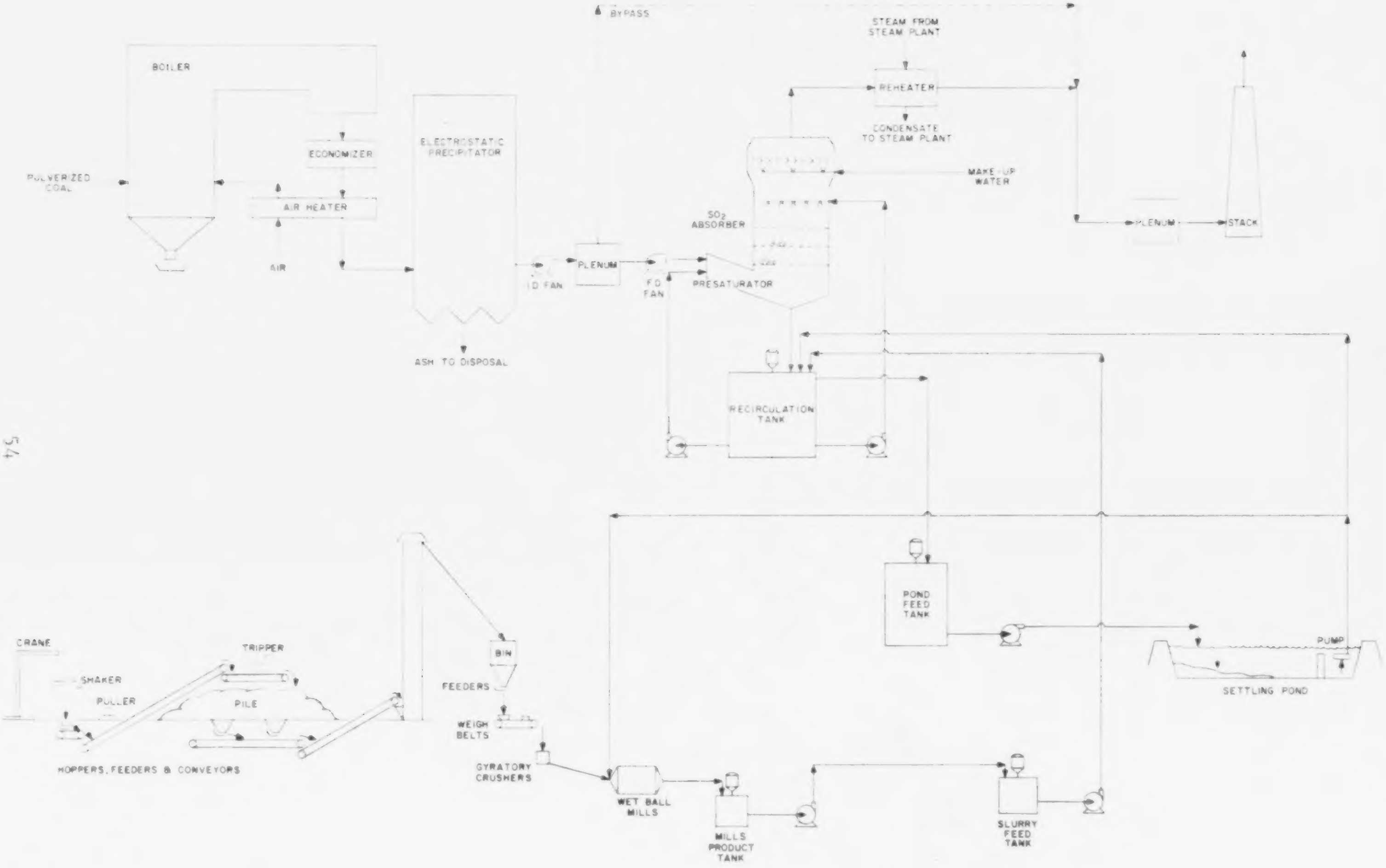
BYPASS
STEAM FROM STEAM PLANT
REHEATER
CONDENSATE TO STEAM PLANT
MAKE-UP WATER
BOILER
PULVERIZED COAL
ECONOMIZER
AIR HEATER
AIR
ELECTROSTATIC PRECIPITATOR
ASH TO DISPOSAL
ID FAN
PLENUM
FD FAN
SO_2 ABSORBER
PRESATURATOR
PLENUM
STACK
RECIRCULATION TANK
POND FEED TANK
PUMP
SETTLING POND
CRANE
SHAKER
PULLER
TRIPPER
PILE
HOPPERS, FEEDERS & CONVEYORS
BIN
FEEDERS
WEIGH BELTS
GYRATORY CRUSHERS
WET BALL MILLS
MILLS PRODUCT TANK
SLURRY FEED TANK

Figure 11. Flow diagram for limestone slurry FGD process.

disposal pond. Pond water is returned to the limestone and scrubber sections for reuse. Makeup water is added to the system as washing water to the mist eliminators.

In most FGD conceptual-design evaluations, no flue gas bypasses the SO_2 absorber or the reheater. The bypass shown in Figure 12 is associated with the coal cleaning - FGD combination processes for sulfur removal.

Flue Gas Bypass, FGD, and Reheat--

The flue gas bypass (Figure 11) is an insulated duct, with control damper, which branches from the plenum at the upstream side of the FGD system and rejoins the main flue gas duct downstream of the reheater. Thus, bypassed gas avoids the FD fan, the SO_2 absorber, the mist eliminator, and the reheater. Since the bypassed gas encounters only duct resistance, its flow can be provided by the slight static pressure in the upstream plenum. A single bypass duct serves all FGD trains of a boiler unit and, since the gas is hot (300°F) and almost dust free, no corrosion-resistant materials are required.

The distribution to the bypass duct is controlled by its control damper which is actuated by an SO_2 analyzer located at the downstream plenum. If the SO_2 content of the flue gas to the stack tends to exceed the requirement of the emission standard, the bypass control damper closes slightly to proportion less flue gas to the bypass and more to the SO_2 absorber. A temperature controller adjusts the steam flow to the reheater to maintain 175°F in the recombined flue gas to the stack.

Figure 12 shows the basis for meeting NSPS using partial FGD scrubbing. When cleaned coals from PCC I, for illustration, are burned in a power plant with FGD, the sulfur rate to the FGD scrubbers is taken at 95% of that to the boiler. As a premise, 5% of the sulfur in the fired coal is removed with ash. The required sulfur removal is indicated by the space between the line showing sulfur rate to the FGD scrubbers and the line showing the NSPS rate to stack emissions. At all levels of sulfur in coal, this needed removal is less than the 90% removal capability which the study assumes for scrubbers themselves. The difference is the latitude for bypassing a portion of the flue gas while maintaining the 90% removal level from flue gas handled by the scrubber. Scrubber size is reduced accordingly. Reheating requirements are those for heating scrubber exit gas at 124°-130°F to a temperature which, when combined with the bypassed gas at 300°F, will provide 175°F in the recombined flue gases to the stack. Evaporation of carryover spray in the exit gas from the scrubber mist eliminator is included as a heat requirement.

Results for bypass, FGD, and reheater requirements are given in Table 13 for the four coals used in the three FGD combination processes with both 1.2 lb SO_2/MBtu and 85% SO_2 removal emission levels. The relationship between bypassing and reheating is plotted in Figure 13. The extrapolation shows that no reheating is required when about 30% of

TABLE 13. AMOUNTS OF BYPASSING, FGD, AND REHEATING

FOR COAL CLEANING - FGD PROCESSES
(2000-MW power Plant)

Sulfur coal, %	1.2 lb SO_2/MBtu NSPS Percent bypassed	Percent scrubbed	FGD, MW	Percent reheat	85% SO_2 removal Percent bypassed	Percent scrubbed	FGD, MW	Percent reheat
PCC I-FGD								
0.7	-	0	0	0	11.8	88.2	1,760	59.4
2.0	61.4	38.6	770	0	18.9	81.1	1,620	43.9
3.5	26.4	73.6	1,470	11.8	16.9	83.1	1,660	36.9
5.0	13.6	86.4	1,730	53.4	13.6	86.4	1,730	54.3
KVB-FGD								
0.7	-	0	0	0	37.1	63.9	1,280	0
2.0	-	0	0	0	57.0	43.0	860	0
3.5	82.8	17.2	340	0	56.6	43.4	870	0
5.0	59.0	41.0	820	0	59.0	41.0	820	0
PCC I-KVB-FGD								
0.7	-	0	0	0	34.3	65.7	1,310	0
2.0	-	0	0	0	67.7	32.3	650	0
3.5	89.7	10.3	200	0	60.0	40.0	800	0
5.0	68.6	31.4	630	0	68.6	31.4	630	0

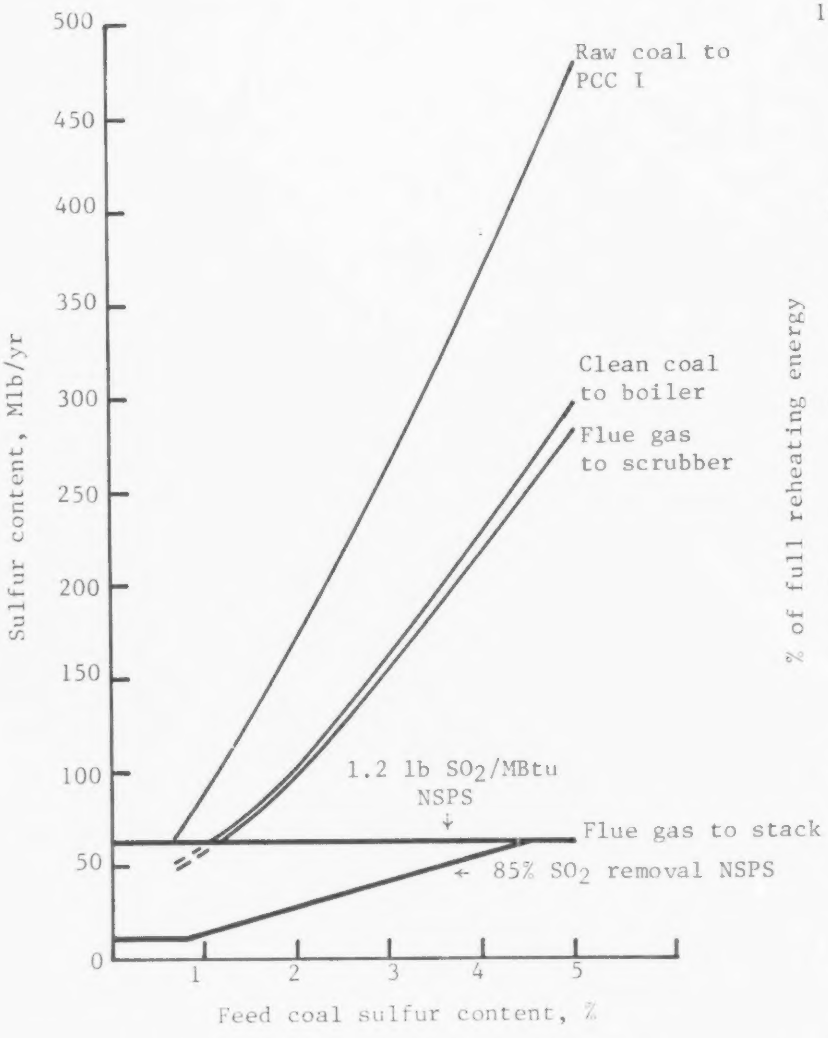

Figure 12, Sulfur distribution in PCC I-FGD combination.

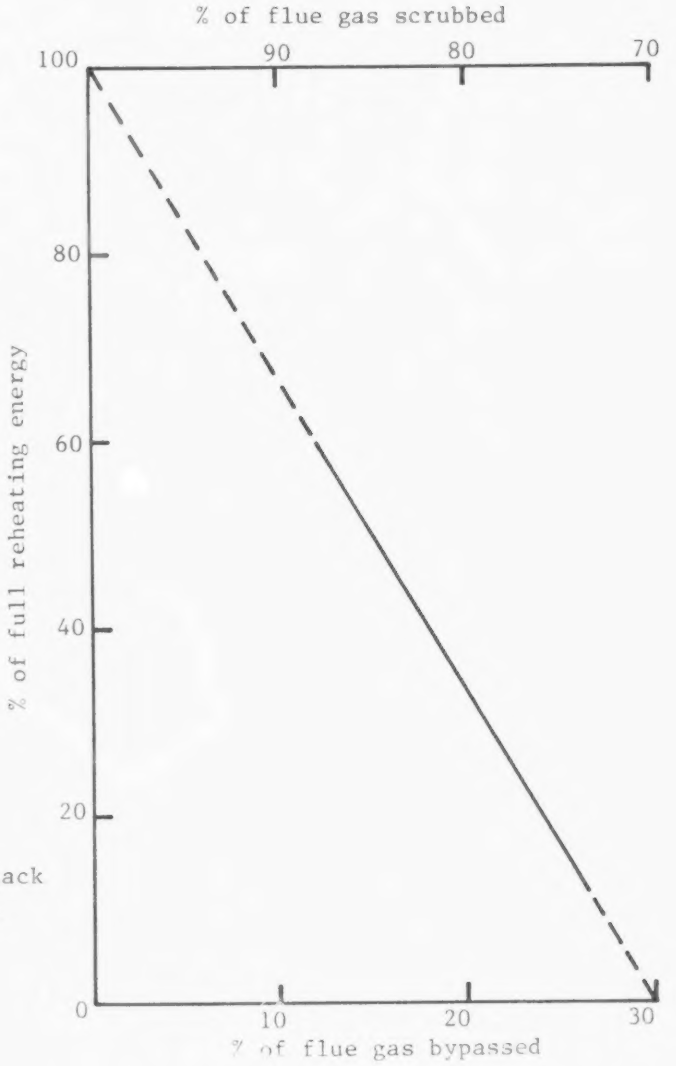

Figure 13. Dependence of flue gas reheating energy on proportion of flue gas bypassed.

the flue gas is bypassed under the temperature conditions of these processes. This bypass level is exceeded (Table 13) in two PCC I-FGD situations and in all KVB-FGD and PCC I-KVB-FGD variations--they require no steam-heated reheating. In 5 of 12 cases, all for the 1.2 lb SO_2/MBtu emission level, coal cleaning meets the emission standard without FGD.

Cleaning Performance and Costs

Since each combination is designed to meet the 1.2 lb SO_2/MBtu emission level or 85% reduction, the overall performance of each combination is a sulfur reduction to the stack emission limit of that standard. For the 1.2 lb SO_2/MBtu standard, the limit is 1.2 lb SO_2/MBtu of fired coal; for 85% removal, it is 15% of the SO_2 equivalent in the raw coal feed to the coal-cleaning process.

No distinctive base case occurs in these combinations. The entire set of costs for total capital investment and annual revenue requirements is tabulated in Appendix B.

RESULTS

COAL-CLEANING PERFORMANCE

Performance Criteria

In this study the primary objective of coal cleaning is assumed to be meeting the power plant emission standards and the criteria for measuring coal-cleaning performance are oriented to that objective. However, no single criterion gives a complete gauge of process effectiveness because of the nature of the criteria and the nature of the emission standards themselves.

The primary criterion used in this study is effectiveness in meeting NSPS. The 1.2 lb SO_2/MBtu NSPS (Federal Register, 1976) in effect at the time of this study are used as one basis of comparison. In anticipation of revision of Federal emission standards the 85% removal NSPS proposed in 1978 (Federal Register, 1978) is also used. These two bases permit projections of the comparisons to emission regulations which differ, within limits, from these NSPS without affecting the validity of the conclusions.

The moisture basis also can be important. Depending on the nature of expression and on the convention being followed, data may be expressed relative to coal which is moisture free (bone dry), air dried (normal internal moisture but essentially no surface moisture), or at actual moisture content (normal internal moisture and actual surface moisture). In this report, equipment performances and the base-case material balances have recognized actual moisture conditions, but the summary data are expressed on a moisture-free basis. Use of the moisture-free basis is simpler, more flexible, and conventional for these purposes, but it can be an oversimplification when moisture differences are large, such as between bituminous and subbituminous coals.

Within the scope of the study, no allowance is made for the variability of sulfur in coal and of FGD removal efficiencies. The data are on the basis of continuous operation without higher performance that might be required for a limited time.

Cleaning Performance

The detailed cleaning performances of each PCC process, each CCC process, and the PCC-CCC process are shown for the four coals in the respective process description sections. The cleaning performances of the seven processes with coals with 0.7%, 2.0%, 3.5% and 5.0% sulfur are shown in Tables 14-17.

TABLE 14. CLEANING PERFORMANCE OF PHYSICAL AND CHEMICAL COAL-CLEANING PROCESSES

0.7% SULFUR COAL

(MOISTURE-FREE BASIS)

		Clean coal						
		Physical cleaning			Chemical cleaning			Combination
	Raw coal	PCC I	PCC II	PCC III	KVB	TRW Gravichem	Kennecott	PCC I-KVB
Total sulfur, %	0.70	0.62	0.62	0.63	0.37	0.50	0.45	0.36
Pyritic sulfur, %	0.24	0.16	0.16	0.17	0.01	0.005	0.03	0.003
Organic sulfur, %	0.45	-	-	-	0.32	0.45	0.38	0.32
Sulfate sulfur, %	0.01	-	-	-	0.04	0.04	0.04	0.04
Ash, %	11.5	7.9	7.4	8.1	11.2	11.3	11.1	7.7
Btu/lb	11,700	12,200	12,300	12,200	11,800	11,700	10,800	12,300
Btu recovery, %	-	95.1	95.3	94.6	99.9	99.5	94.9	95.0
Weight recovery, %	-	91.1	90.9	90.9	99.4	99.5	102.8	90.7
Total sulfur, lb/MBtu	0.60	0.51	0.50	0.52	0.31	0.43	0.42	0.29
Sulfur removal, % Btu basis	-	15	17	13	48	28	30	52

TABLE 15. CLEANING PERFORMANCE OF PHYSICAL AND CHEMICAL COAL-CLEANING PROCESSES

2% SULFUR COAL

(MOISTURE-FREE BASIS)

		Clean coal						
		Physical cleaning			Chemical clearing			Combination
	Raw coal	PCC I	PCC II	PCC III	KVB	TRW Gravichem	Kennecott	PCC I-KVB
Total sulfur, %	2.0	1.36	1.33	1.42	0.53	0.78	0.73	0.53
Pyritic sulfur, %	1.32	0.68	0.65	0.74	0.03	0.03	0.15	0.02
Organic sulfur, %	0.64	-	-	-	0.46	0.66	0.54	0.47
Sulfate sulfur, %	0.04	-	-	-	0.04	0.04	0.04	0.04
Ash, %	14.5	7.5	7.1	8.1	13.3	13.4	13.8	6.8
Btu/lb	13,000	14,000	14,100	13,900	13,400	13,300	12,100	14,200
Btu recovery, %	-	93.1	92.9	93.0	99.5	99.6	95.2	92.8
Weight recovery, %	-	86.0	85.5	86.4	96.9	97.3	102.6	84.5
Total sulfur, lb/MBtu	1.54	0.97	0.94	1.02	0.40	0.59	0.60	0.37
Sulfur removal, % Btu basis	-	37	39	34	74	62	61	76

TABLE 16. CLEANING PERFORMANCE OF PHYSICAL AND CHEMICAL COAL-CLEANING PROCESSES

3.5% SULFUR COAL

(MOISTURE-FREE BASIS)

		Clean coal						
		Physical cleaning			Chemical cleaning			Combination
	Raw coal	PCC I	PCC II	PCC III	KVB	TRW Gravichem	Kennecott	PCC I-KVB
Total sulfur, %	3.50	2.55	2.50	2.63	1.00	1.47	1.34	0.98
Pyritic sulfur, %	2.22	1.27	1.22	1.35	0.05	0.05	0.26	0.03
Organic sulfur, %	1.23	-	-	-	0.91	1.29	1.04	0.91
Sulfate sulfur, %	0.05	-	-	-	0.04	0.04	0.04	0.04
Ash, %	14.0	8.0	7.7	8.5	11.9	11.9	13.2	6.7
Btu/lb	12,700	13,600	13,700	13,600	13,300	13,300	11,900	14,100
Btu recovery, %	-	92.2	92.1	92.2	99.2	99.3	94.8	91.8
Weight recovery, %	-	86.2	85.8	86.7	94.7	95.2	101.5	82.6
Total sulfur, lb/MBtu	2.76	1.87	1.83	1.94	0.75	1.11	1.13	0.70
Sulfur removal, % Btu basis	-	32	33	29	73	60	59	75

TABLE 17. CLEANING PERFORMANCE OF PHYSICAL AND CHEMICAL COAL-CLEANING PROCESSES

5% SULFUR COAL

(MOISTURE-FREE BASIS)

		Clean coal						
		Physical cleaning			Chemical cleaning			Combination
	Raw coal	PCC I	PCC II	PCC III	KVB	TRW Gravichem	Kennecott	PCC I-KVB
Total sulfur, %	5.00	3.67	3.51	3.78	1.32	1.95	1.81	1.26
Pyritic sulfur, %	3.35	2.02	1.86	2.13	0.07	0.07	0.40	0.04
Organic sulfur, %	1.59	-	-	-	1.21	1.70	1.37	1.18
Sulfate sulfur, %	0.06	-	-	-	0.04	0.04	0.04	0.04
Ash, %	16.7	10.1	9.3	10.6	13.7	13.6	15.8	8.0
Btu/lb	12,000	13,000	13,100	12,900	12,900	12,900	11,300	13,600
Btu recovery, %	-	90.7	91.4	90.7	98.8	98.9	94.1	89.6
Weight recovery, %	-	84.2	84.0	84.7	92.1	92.8	100.1	80.1
Total sulfur, lb/MBtu	4.17	2.84	2.68	2.93	1.02	1.51	1.60	0.93
Sulfur removal, % Btu basis	-	32	36	30	76	64	62	78

PCC Processes--

The cleaning performances of the three PCC processes are generally similar for the bituminous coals with 2.0%, 3.5%, and 5% sulfur, but all are distinctly lower for the subbituminous coal with 0.7% sulfur. In the bituminous coals, 63% to 67% of the total sulfur content is pyritic sulfur and hence available for physical separation when liberated from coal particles. In the 0.7% sulfur coal only 34% of total sulfur is pyritic and potentially separable by PCC.

PCC I and PCC III provide sulfur removals (expressed as the percentage of reduction from lb sulfur/MBtu in the raw coal to lb sulfur/MBtu in the clean coal) of 29% to 37% for the bituminous coal. These removals occur at the relatively high Btu recoveries of 91% to 93%. They would be slightly higher at lower Btu recovery. For PCC II, the corresponding sulfur removals for the ultraclean coal product are 46% to 51% and for the middling product they are 21% to 25%. On a combined basis, sulfur removals for PCC II are from 33% to 39%. Total Btu recoveries for the bituminous coals in PCC II are also at 91% to 93%. With all PCC processes, the heating value of the coal is substantially increased by the removal of ash diluent and only slightly reduced by the loss of heat of combustion of pyrite.

The removal of sulfate sulfur was disregarded as an item of cleaning performance in the PCC processes. Sulfur as sulfate amounts to only 0.04% to 0.06% of the raw bituminous coals and its removal to refuse is controlled by the distribution of water between the clean coal and refuse products. Typically, 20% to 35% of the sulfate sulfur is removed in the refuse. No organic sulfur is considered to be removable by PCC except for the small amount trapped in the coal lost with the refuse.

With the subbituminous coal containing 0.7% sulfur, PCC I, PCC II, and PCC III reduce the pyritic sulfur from 13% to 17%. For all PCC processes, cleaning performance with subbituminous coal is limited by the high ratio of organic sulfur to total sulfur as well as by particle size. Tests reported by Cavallaro et al. (1976) show a substantially improved sulfur removal from western coals when the top size is 14 mesh rather than 1-1/2 inch or 3/8 inch. Such size reduction would be a costly and usually undesirable commercial practice. It is apparent that optimum pyrite removal from the 0.7% sulfur coal requires conditions of particle size and specific gravity of separation specifically tailored to subbituminous coals rather than the generalized conditions of the PCC processes as evaluated.

CCC and PCC-CCC Processes--

Almost all of the pyritic sulfur is removed by the KVB and TRW processes and a very high proportion of it is removed by the Kennecott process. Removal of organic sulfur varies from none (TRW), to low (Kennecott), to moderate (KVB). All three processes leave a low residual amount of sulfate sulfur. The TRW process also generates a small amount of elemental sulfur in the clean coal. Total sulfur removal therefore depends largely on the proportion of pyritic to organic sulfur in the coal. Qualitatively, KVB removes the highest percentage of total sulfur, followed in effectiveness by Kennecott and TRW.

With the bituminous coals, the CCC processes have a sulfur removal efficiency of 59% to 76%, which is twice the comparable removal by the PCC processes. The PCC I-KVB combination has a 75% to 78% sulfur removal efficiency. Sulfur removal from the 0.7% subbituminous coal is lower than for the bituminous coals because of the higher ratio of organic to pyritic sulfur.

Coal Cleaning to NSPS

For further comparison of coal-cleaning performance, the emission control capabilities for the seven cleaning processes are shown in Figure 14 for each of the four coals evaluated. The figure shows the relationships between sulfur in stack emissions and sulfur in raw coal when burning either the raw coal or the same coal cleaned by each process. In addition, reference lines are included for the raw coal total sulfur content and for the 1.2 lb SO_2/MBtu and the 85% reduction emission levels. The sulfur emission plots have slight curvatures because of variations in calorific value from coal to coal. On these bases, the chart shows the raw coal sulfur levels that can be sufficiently reduced by the various processes to meet emission limits.

No combinations of the coals and cleaning processes meet the 85% reduction NSPS. The 1.2 lb SO_2/MBtu emission level can be met by each cleaning process (and without cleaning) if the sulfur content of the raw coal is within the limits shown in Table 18. With no coal cleaning, the standard is met by a raw coal with 0.7% sulfur and 11,700 Btu/lb. The same NSPS can be met at raw coal sulfur contents up to 1.0% to 1.7% by the PCC processes, up to 2.0% to 3.1% by the CCC processes, and up to 3.3% by the PCC I-KVB combination process. In these cases, the raw coal heating values were up to 12,800 Btu/lb.

TABLE 18. MAXIMUM SULFUR IN RAW COAL FOR MEETING

PRE-1978 NSPS WITH COAL CLEANING

(MOISTURE-FREE BASIS)

Coal-cleaning process	% S limit in raw coal for meeting pre-1978 NSPS
No cleaning	0.7
PCC II, middling	1.0
PCC III	1.1
PCC I	1.2
PCC II, clean coal	1.7
TRW	2.0
Kennecott	2.0
KVB	3.1
PCC I-KVB	3.3

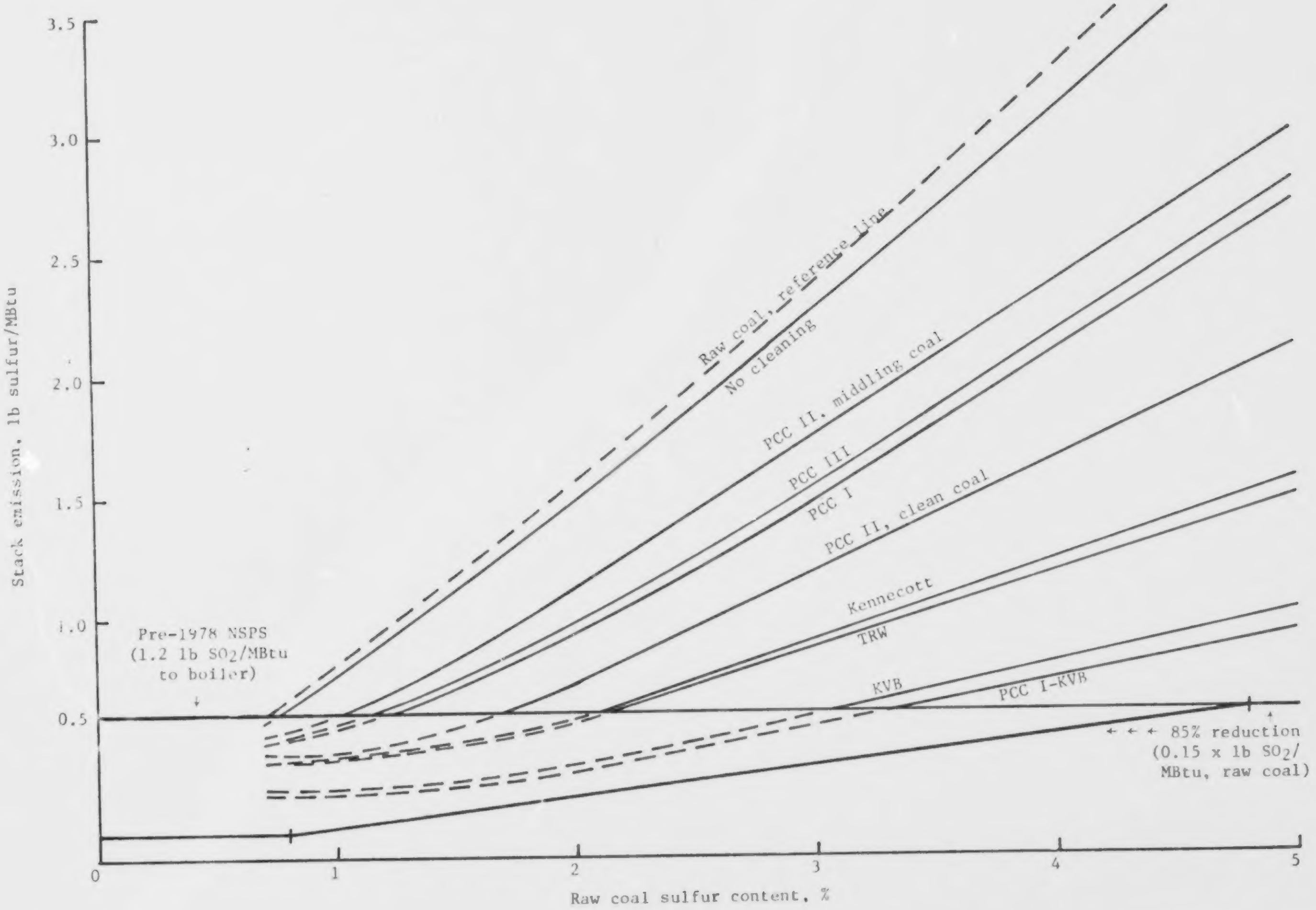

Figure 14. Power plant stack emissions using various cleaned coals without FGD.

When SIP regulations for existing power plants are less stringent than the NSPS, the raw coal sulfur tolerances increase noticeably. For example, at a SIP regulation of 4 lb SO_2/MBtu (2 lb sulfur/MBtu) PCC I can meet the regulation with raw coal containing up to almost 3.9% sulfur.

ECONOMICS

Coal-Cleaning Processes

Detailed capital investment and annual revenue requirements for the seven coal-cleaning processes are included in Appendix B for each of the four coals. Summarized capital investment and annual revenue requirements for each combination of cleaning process and coal are shown in Tables 19 and 20. The capital investments and annual revenue requirements are shown graphically in Figures 15 and 16.

Capital Investment Comparisons--

For the four coals, PCC capital investments range from 31 to 40 $/kW. Similarities among the three processes generally tend to group their investment costs, but process individualities also create some small cost divergences. As similarities, the raw coal tonnages for the three processes and four coals vary only 5% to 6% from the average rate and clean coal tonnage rates vary only 7% to 8% from their average. There are equipment similarities in crushing and sizing, in the use of DM cyclones on the largest in-process stream, and in the types of dewatering equipment. The change in capital investment with raw coal sulfur content is due not to the sulfur content itself but to the heating values and cleaning responses of the coals represented by these sulfur contents. Within each PCC process, capital investment decreases with decreasing coal sulfur content from the 5% to the 3.5% to the 2% sulfur coal in the same order as the tonnage rates of raw and clean coals decrease. It increases from the 2% to the 0.7% sulfur coals with an increase in tonnage rate caused by lower heating value, higher inherent moisture content, and differences in cleaning response at the single specific gravity used for all coal separations. Among the three PCC processes, capital investment increases from PCC I to PCC III to PCC II as the top size of the in-process coal for the three processes decreases from 2 to 1-1/2 to 3/4 inches, and as the proportion of fine coal increases. This feature helps to make PCC I the lowest cost PCC process for coals which are acceptably cleanable at the top sizes used by DM vessels. Other cost differences among the PCC processes result from differences in type of equipment and, quite importantly, to the stream sizes on which the equipment is used.

Capital investments for the CCC processes are higher and more individualistic than those of the PCC processes. All CCC processes incur the higher costs associated with the grinding, sizing, and processing of relatively fine coal. Capital investment for the KVB process is the lowest of the CCC processes. The KVB process operates at atmospheric pressure and at low temperature but it has moderately high costs for reactor off-gas cleaning and for product agglomeration. Its total

TABLE 19. COAL CLEANING PROCESSES

CAPITAL INVESTMENT SUMMARY

Process	% S in coal	M$ investment	$/kW	¢/lb S removed
PCC I	0.7	64.7	32.4	517.1
	2	62.9	31.4	86.8
	3.5	63.6	31.8	54.4
	5	67.4	33.7	36.5
PCC II	0.7	77.4	38.7	573.3
	2	75.3	37.6	99.2
	3.5	76.0	38.0	62.3
	5	79.9	39.9	40.4
PCC III	0.7	76.5	38.3	608.7
	2	73.4	36.7	107.6
	3.5	74.4	37.2	67.9
	5	78.7	39.4	45.0
KVB	0.7	148.9	74.5	507.7
	2	152.0	76.0	126.8
	3.5	162.7	81.3	76.6
	5	171.4	85.7	51.0
TRW	0.7	221.1	110.5	1,239.8
	2	218.7	109.4	218.9
	3.5	223.1	111.6	128.0
	5	228.0	114.0	78.2
Kennecott	0.7	269.2	134.6	1,214.4
	2	259.2	129.6	243.6
	3.5	268.3	134.2	144.2
	5	281.2	140.6	93.7
PCC I-KVB	0.7	197.7	98.9	553.9
	2	201.5	100.7	149.5
	3.5	212.3	106.2	88.1
	5	229.4	114.7	59.3

TABLE 20. COAL CLEANING PROCESSES

ANNUAL REVENUE REQUIREMENT SUMMARY[a]

Process	% S in coal	M$ requirement	Mills/kWh	¢/lb S removed
PCC I	0.7	23.5	2.1	188
	2	24.3	2.2	33.5
	3.5	26.1	2.4	22.3
	5	30.2	2.7	16.3
PCC II	0.7	26.7	2.4	197.6
	2	27.7	2.5	36.5
	3.5	29.4	2.7	24.1
	5	32.2	2.9	16.3
PCC III	0.7	26.3	2.4	212.0
	2	26.1	2.4	38.3
	3.5	27.7	2.5	25.3
	5	31.8	2.9	18.2
KVB	0.7	66.3	6.0	225.9
	2	69.5	6.3	57.9
	3.5	78.5	7.1	37.0
	5	91.7	8.3	27.3
TRW	0.7	73.8	6.7	414.0
	2	74.1	6.7	74.2
	3.5	76.8	7.0	44.0
	5	79.8	7.3	27.4
Kennecott	0.7	140.7	12.8	634.7
	2	135.7	12.4	127.5
	3.5	139.3	12.7	74.9
	5	161.5	14.7	53.8
PCC I-KVB	0.7	92.1	8.4	258.0
	2	96.2	8.8	71.4
	3.5	109.3	9.9	45.4
	5	121.8	11.0	31.5

[a] Does not include other economic benefits of using cleaned coal.

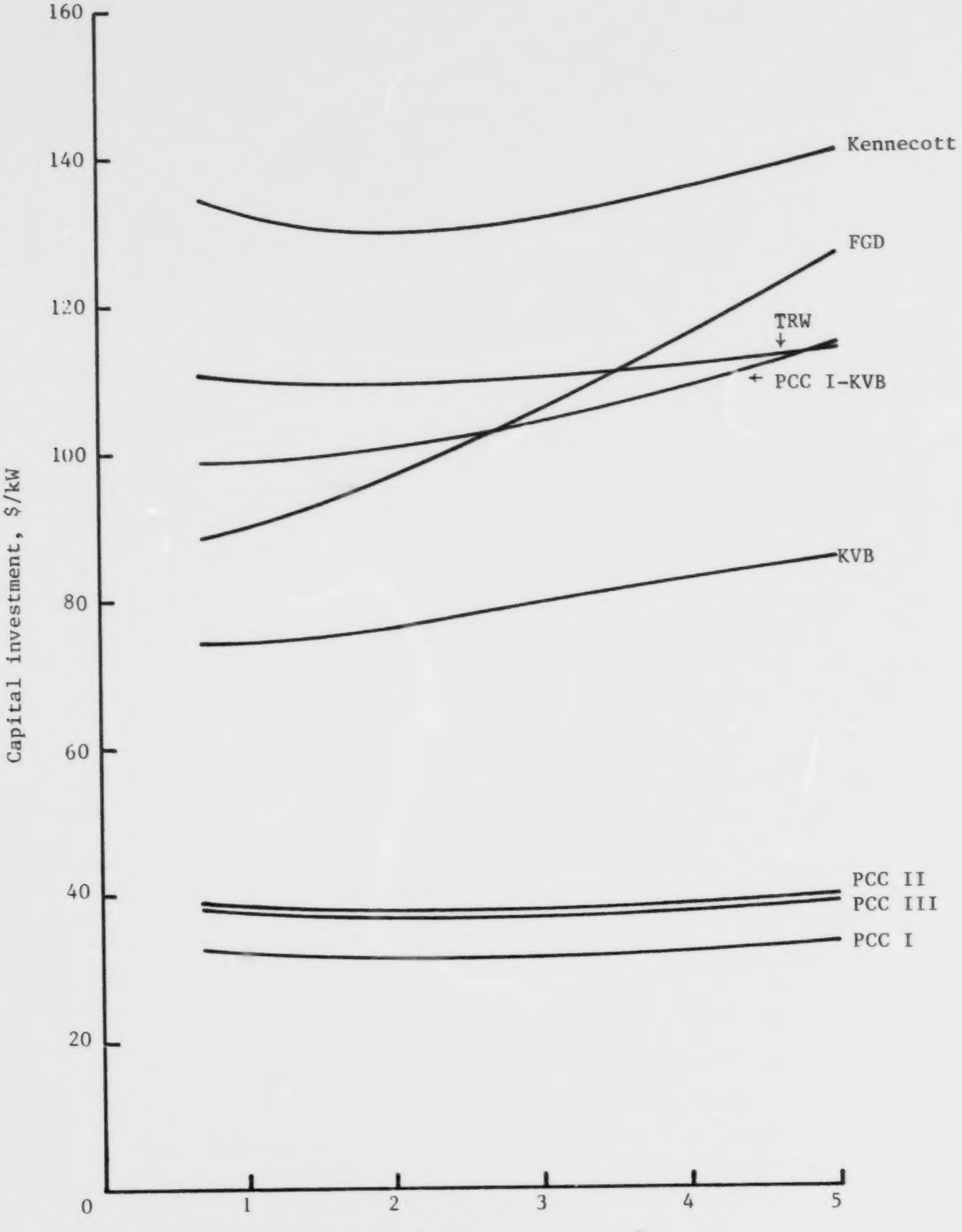

Figure 15. Capital investment for coal-cleaning processes and FGD.

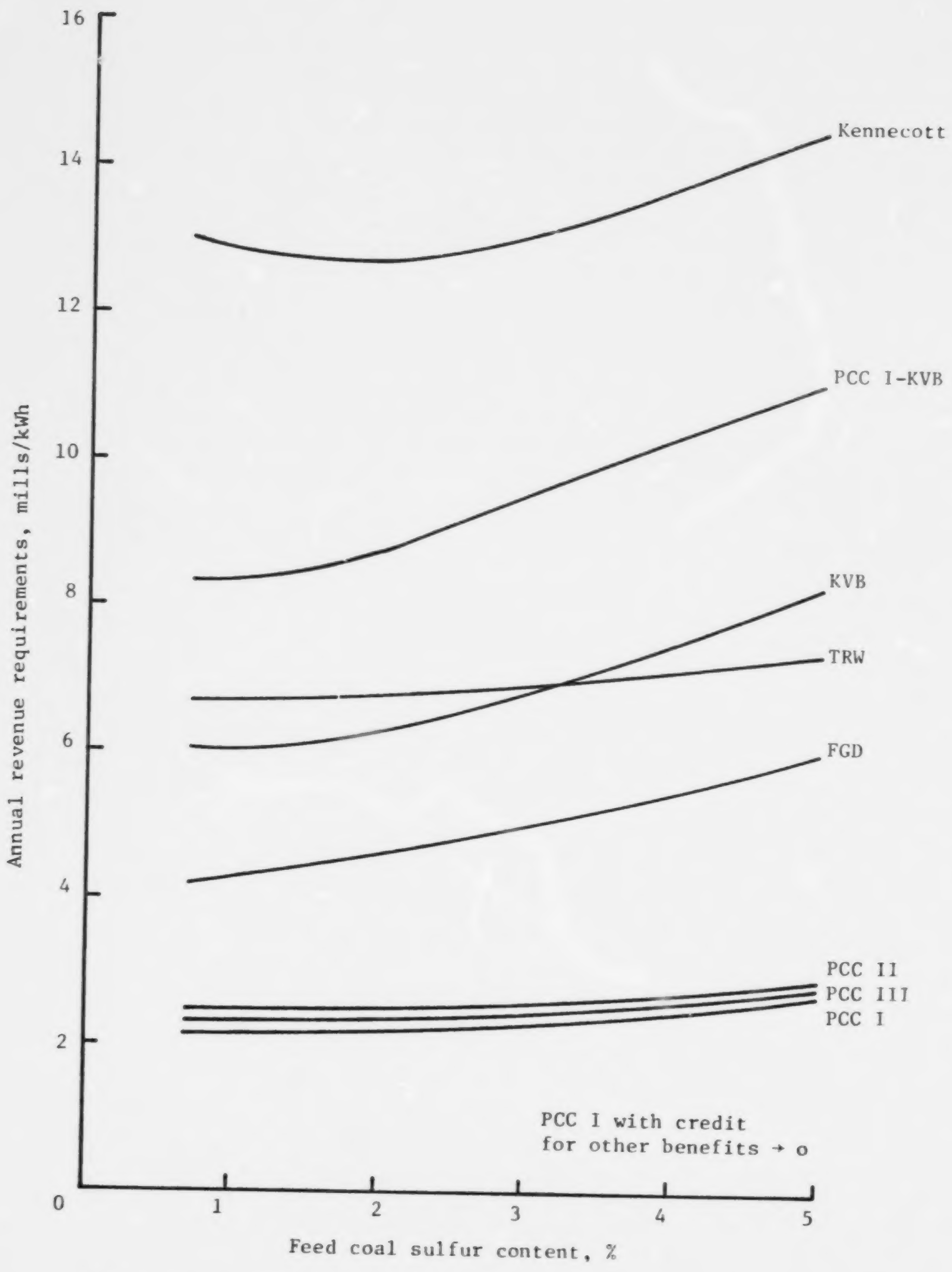

Figure 16. Annual revenue requirements for coal-cleaning processes and FGD.

capital investment of 75 to 86 \$/kW has a moderate sensitivity to raw coal sulfur level. The TRW Gravichem process has about the same product agglomeration cost as the KVB but it has high costs in the reactor - regenerator area and in the acetone leaching and recovery system. These factors bring its total capital investment to 109 to 114 \$/kW, with a low sensitivity to raw coal sulfur content. In the Kennecott process, the reactor area, the coal filtration area, and agglomeration and drying areas are costly and the total capital investment is 130 to 141 \$/kW with a moderate sensitivity to raw coal sulfur content. The Kennecott process is the most capital intensive of the coal-cleaning processes studied.

In the PCC I-KVB combination process, the two processes operate as separate systems and the total capital investment is almost additive. Some cost economy occurs in the KVB section because of the raw coal crushing and sizing done in the PCC I operation. There is also some saving in coal storage. In the combination process, the clean coal storage of PCC I process and the raw coal storage of the KVB process are replaced by an interim storage area which bridges the different operating schedules and provides surge capacity. The resulting total capital investment is 99 to 115 \$/kW, which is more than 90% of the sum for the separate units.

Annual Revenue Requirements--

As Figure 16 shows, the annual revenue requirements of the PCC processes are closely grouped between 2.1 and 2.9 mills/kWh. The indirect cost category, principally capital charges, makes up about 35% to 45% of these totals. In the direct cost category, the coal loss to refuse is roughly two to three times the conversion costs and it is a third to a half of total annual revenue requirements. This high cost of coal loss emphasizes the importance of recovery efficiency because these coal-loss costs occur even at the relatively high weight recoveries of 84% to 87% for the bituminous coals and about 91% for the 0.7% sulfur coal. The accompanying Btu recoveries are 91% to 93% for the bituminous coals and about 95% for the 0.7% sulfur coal. For each PCC process, the largest items of conversion costs are operating labor, maintenance, electricity, and magnetite loss.

In contrast with the PCC processes, the annual revenue requirements for the CCC group are highly specific to the process, the coal, and the sulfur removed. When 0.7% to 5% sulfur coals are treated by the KVB process, direct costs comprise 67% to 73% of the total annual revenue requirements of 6.0 to 8.3 mills/kWh. The conversion cost changes little with coal sulfur content because the largest cost components, steam and electricity, depend more on the slightly varying coal rate than on the widely varying sulfur content. However, the raw material cost changes markedly with coal sulfur content because of sodium hydroxide, lime, and oxygen requirements. The binder cost (sodium lignin sulfonate) follows the coal rate and varies only slightly with coal sulfur content. KVB has recently reported that further development work on their process has made significant improvement in the sodium hydroxide usage. This will make a sizeable reduction in the annual revenue requirement for the KVB process.

Compared with the KVB process, the annual revenue requirements of the TRW process, 6.7 to 7.3 mills/kWh, are higher for low-sulfur coals and lower for high-sulfur coals. The TRW process has indirect costs of about 3 mills/kWh and direct costs of 3.7 to 4.4 mills/kWh. The raw material costs are only 0.2 to 1.2 mills/kWh but the conversion costs include the very high steam requirement of 1.6 to 1.9 mills/kWh and electricity and maintenance costs of 1.3 mills/kWh.

Of the three CCC processes, the Kennecott process has the highest annual revenue requirements in all major categories. Its raw material costs are 2.2 to 4.4 mills/kWh, mainly for oxygen and the agglomeration binder; its conversion costs are 6.5 to 7.0 mills/kWh, mainly for steam and electricity; its indirect costs are 3.4 to 3.7 mills/kWh, mainly because of its high capital investment. The total is 12.4 to 14.7 mills/kWh.

Annual revenue requirements of the PCC I-KVB combination process are similar to the combined amounts for the separate processes. The combination has the cost pattern of the KVB process and its annual revenue requirements are about 40% greater.

The annual revenue requirements shown in Figure 16 do not include credit for other economic benefits (and a few penalties) of using cleaned coal. When the 5% sulfur coal is cleaned by the PCC I process, the cleaned coal will have approximately a 2 mill/kWh economic advantage over the raw coal when credits are given for reductions in ash disposal, coal transportation, boiler maintenance, peaking capacity, rated capacity, and plant availability (Phillips and Cole, 1979). The effect of these economic benefits is shown as a single point for the 5% sulfur coal in Figures 16, 20, and 22. It should be cautioned that the actual levels of cost benefits are uncertain, even for site-specific cases. Further work to identify and quantify these factors is underway in joint programs with DOE, EPA, and TVA.

Effect of Coal Sulfur Content on Economics--

Figure 17 shows the effect of coal sulfur content on the capital costs of the six coal-cleaning processes and on limestone scrubbing FGD. Annual revenue requirements are shown in Figure 18. Since the processes remove different percentages of sulfur from the raw coal, capital and operating costs per kilowatthour are not comparable on a direct basis. The cost comparisons are shown on the basis of quantity of sulfur removed, which incorporates removal efficiency. The three PCC processes and the KVB process have lower capital costs per pound of sulfur removed per year than FGD. On the same basis the TRW and Kennecott processes have higher capital costs than FGD.

The three PCC processes have annual revenue requirements per pound of sulfur removed similar to FGD except for the 0.7% coal. All of the CCC processes have higher annual revenue requirements per pound of sulfur removed than FGD, the Kennecott process being the highest and KVB being the lowest.

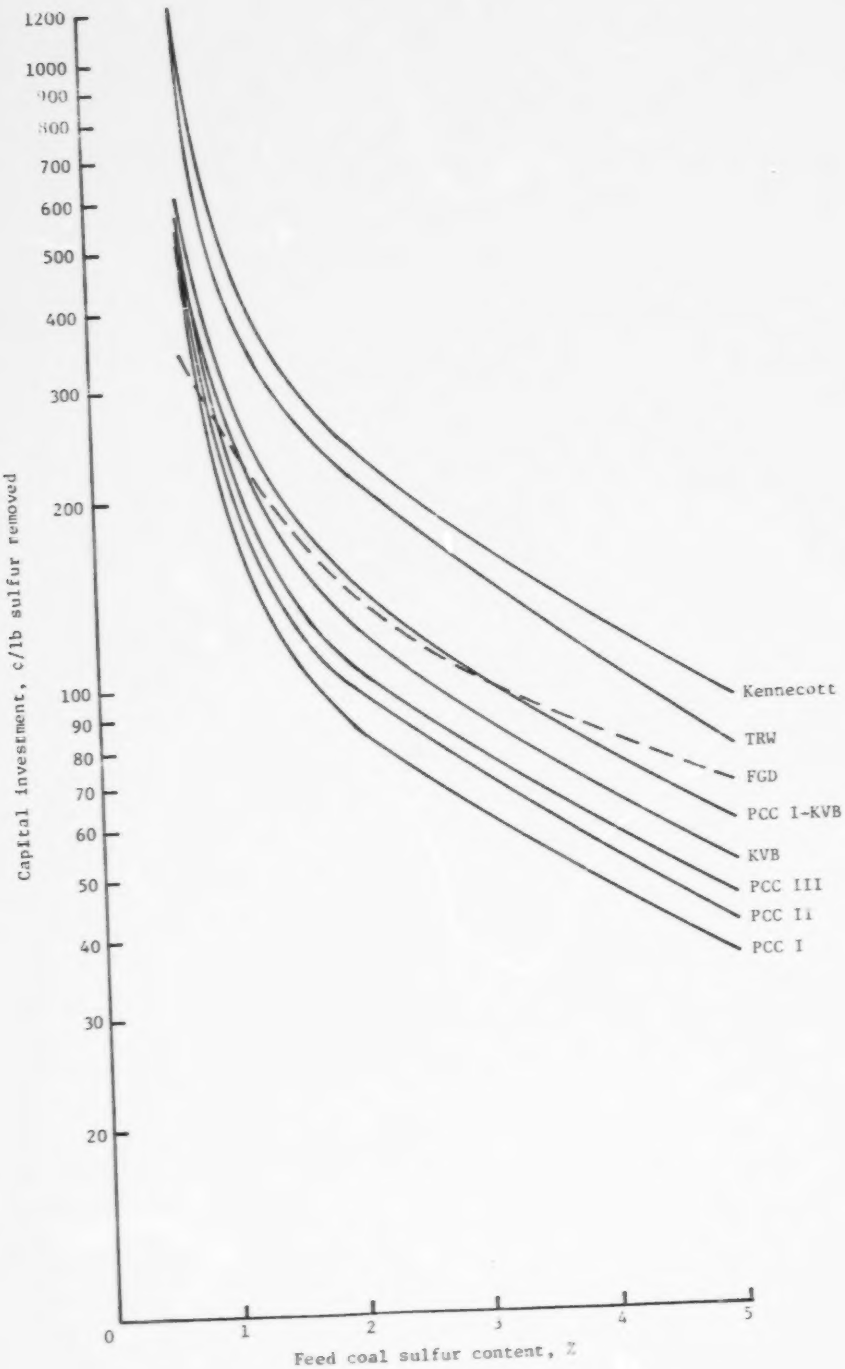

Figure 17. Effect of coal sulfur content on capital investment for coal-cleaning processes.

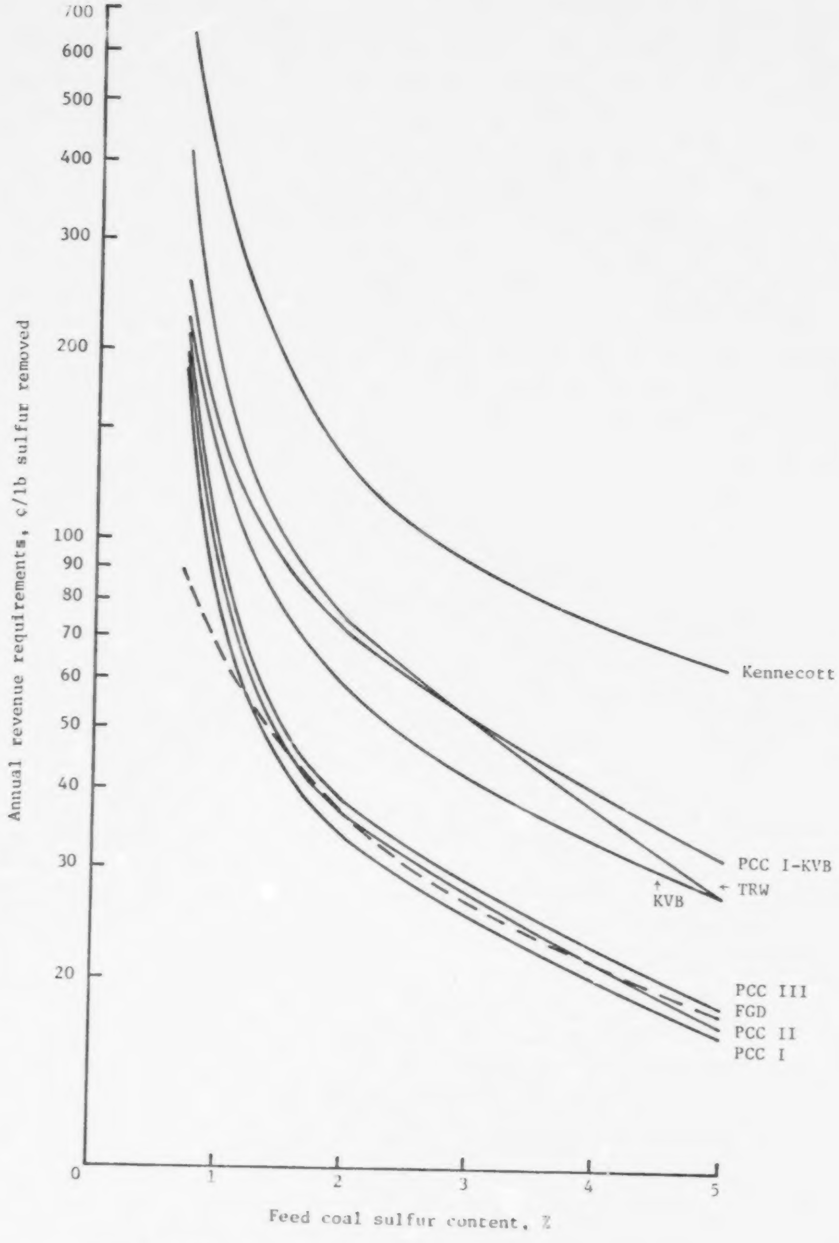

Figure 18. Effect of coal sulfur content on annual revenue requirements for coal-cleaning processes.

Coal Cleaning and FGD Combinations

It has been shown that the clean coal from each cleaning process can meet the 1.2 lb SO_2/MBtu emission level or various SIP standards when the raw-coal sulfur content is within certain limits. However, no combination of coal and cleaning process can meet the 85% SO_2 reduction emission level. To meet the more restrictive 85% reduction NSPS or to meet other standards with a higher sulfur coal, the sulfur removal by coal cleaning must be supplemented by FGD. Such combinations, PCC I-FGD, KVB-FGD, and PCC I-KVB-FGD, have been described. Their economic results are shown in Tables 21-22 and Figures 19-22 for both NSPS.

In Figures 19-20 the previously determined capital investment and annual revenue requirements of PCC I, KVB, and PCC I-KVB are used, up to their coal sulfur limits to meet the 1.2 lb SO_2/MBtu emission level. The FGD costs beyond these limits are associated with burning the cleaned coals and scrubbing and reheating only the portion of the flue gas necessary to meet the NSPS.

When the PCC I process is combined with partial FGD scrubbing the capital investment is less than for FGD alone and annual revenue requirements are approximately the same as for FGD alone. This is true at the same sulfur levels for both emission limits except at low sulfur levels. The potential benefits of using PCC in combination with FGD depend on the characteristics of the individual coal. For coals with higher ratios of pyritic sulfur to organic sulfur or coals with larger pyrite particle sizes, these costs could be lower than for FGD alone. Conversely, coals that have lower ratios of pyritic sulfur to organic sulfur or have very fine pyrite particle sizes could have less expensive SO_2 removal costs using FGD alone.

When coal cleaned by the KVB process is burned, followed by partial FGD scrubbing to meet 1.2 lb SO_2/MBtu emission limits, the capital investment is approximately the same as for FGD alone at the same sulfur level in the raw coal. For sulfur levels in the raw coal below about 3%, the KVB process alone will meet the 1.2 lb SO_2/MBtu emission limits without FGD.

To meet 85% SO_2 removal, the KVB process plus partial FGD scrubbing has a capital investment approximately the same as that of FGD alone for raw coal sulfur levels above about 3%. For lower sulfur levels, the KVB process plus FGD has a higher capital investment than FGD alone. The capital investment required for the PCC I-KVB-FGD case is higher than for PCC I-FGD, KVB-FGD, or FGD alone for both levels of SO_2 removal.

The annual revenue requirements to meet the 1.2 lb SO_2/MBtu emission level with PCC I-FGD are higher than for FGD alone for raw coal sulfur levels above about 3%. Below about 3% coal sulfur levels, the annual revenue requirements for PCC I-FGD are lower than for FGD alone. The annual revenue requirements for KVB-FGD and for PCC I-KVB-FGD are higher than for FGD alone at all raw coal sulfur levels.

TABLE 21. COAL-CLEANING PROCESSES WITH FGD

CAPITAL INVESTMENT SUMMARY

Process	% S in coal	M$ investment	$/kW	¢/lb S removed
85% Removal NSPS				
PCC I and FGD	0.7	194.3	97.1	442.6
	2	195.5	97.8	131.9
	3.5	218.3	109.1	81.9
	5	247.4	123.7	58.7
KVB and FGD	0.7	234.1	117.0	447.5
	2	218.0	109.0	158.6
	3.5	234.7	117.3	94.9
	5.0	258.0	129.0	68.2
PCC I-KVB and FGD	0.7	295.3	147.7	343.3
	2	270.3	135.2	183.4
	3.5	291.8	145.9	109.3
	5.0	298.2	149.1	70.4
FGD, no coal cleaning	0.7	176.6	88.3	341.2
	2	194.3	97.2	141.6
	3.5	221.3	110.6	90.7
	5	254.5	127.3	68.4
1.2 lb SO_2/MBtu NSPS				
PCC I and FGD	0.7	FGD not required		
	2	142.7	71.4	127.7
	3.5	203.5	101.7	81.1
	5	247.4	123.7	58.7
KVB and FGD	0.7	FGD not required		
	2	FGD not required		
	3.5	207.5	103.8	91.0
	5	258.0	129.0	68.2
PCC I-KVB and FGD	0.7	FGD not required		
	2	FGD not required		
	3.5	246.2	123.1	97.9
	5	298.2	149.1	70.4

TABLE 22. COAL-CLEANING PROCESSES WITH FGD

ANNUAL REVENUE REQUIREMENT SUMMARY[a]

Process	% S in coal	M$ requirement	Mills/kWh	¢/lb S removed
85% Removal NSPS				
PCC I and FGD	0.7	59.4	5.4	105
	2	61.0	5.6	41.1
	3.5	68.8	6.3	25.8
	5	80.0	7.3	19.0
KVB and FGD	0.7	91.0	8.3	197.8
	2	88.6	8.1	42.6
	3.5	100.6	9.1	40.1
	5.0	112.3	10.2	29.9
PCC I-KVB and FGD	0.7	114.3	10.4	174.0
	2	109.8	10.0	72.3
	3.5	126.1	11.5	45.3
	5.0	136.8	12.4	35.1
FGD, no coal cleaning	0.7	46.2	4.2	89.3
	2	50.9	4.6	37.1
	3.5	57.8	5.3	23.7
	5	66.2	6.0	17.8
1.2 lb SO_2/MBtu NSPS				
PCC I and FGD	0.7	FGD not required		
	2	45.3	4.1	40.5
	3.5	64.6	5.9	25.7
	5	80.0	7.3	19.0
KVB and FGD	0.7	FGD not required		
	2	FGD not required		
	3.5	93.8	8.5	55.4
	5	112.3	10.2	29.9
PCC I-KVB and FGD	0.7	FGD not required		
	2	FGD not required		
	3.5	122.7	11.2	47.4
	5	136.8	12.4	35.1

[a] Does not include other economic benefits of using cleaned coal except for effect of lower sulfur levels on FGD capital and operating costs.

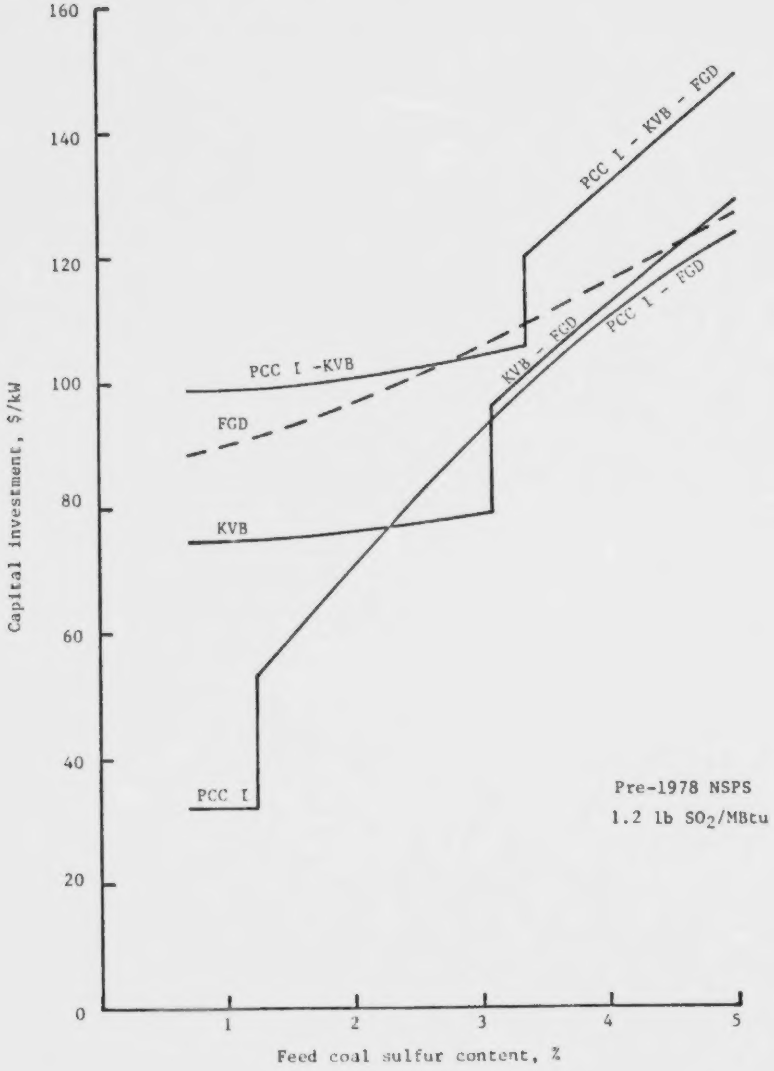

Figure 19. Capital investment to meet 1.2 lb SO_2/MBtu NSPS by coal cleaning and FGD.

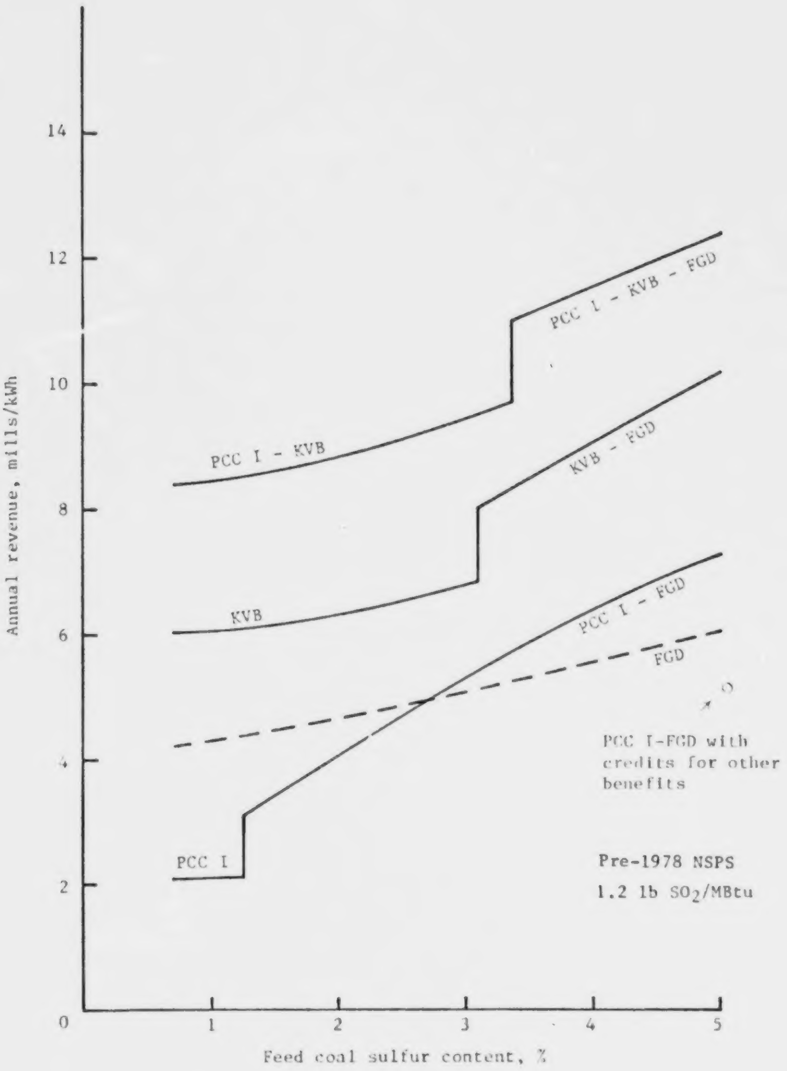

Figure 20. Annual revenue requirements to meet the 1.2 lb SO_2/MBtu NSPS by coal cleaning and FGD.

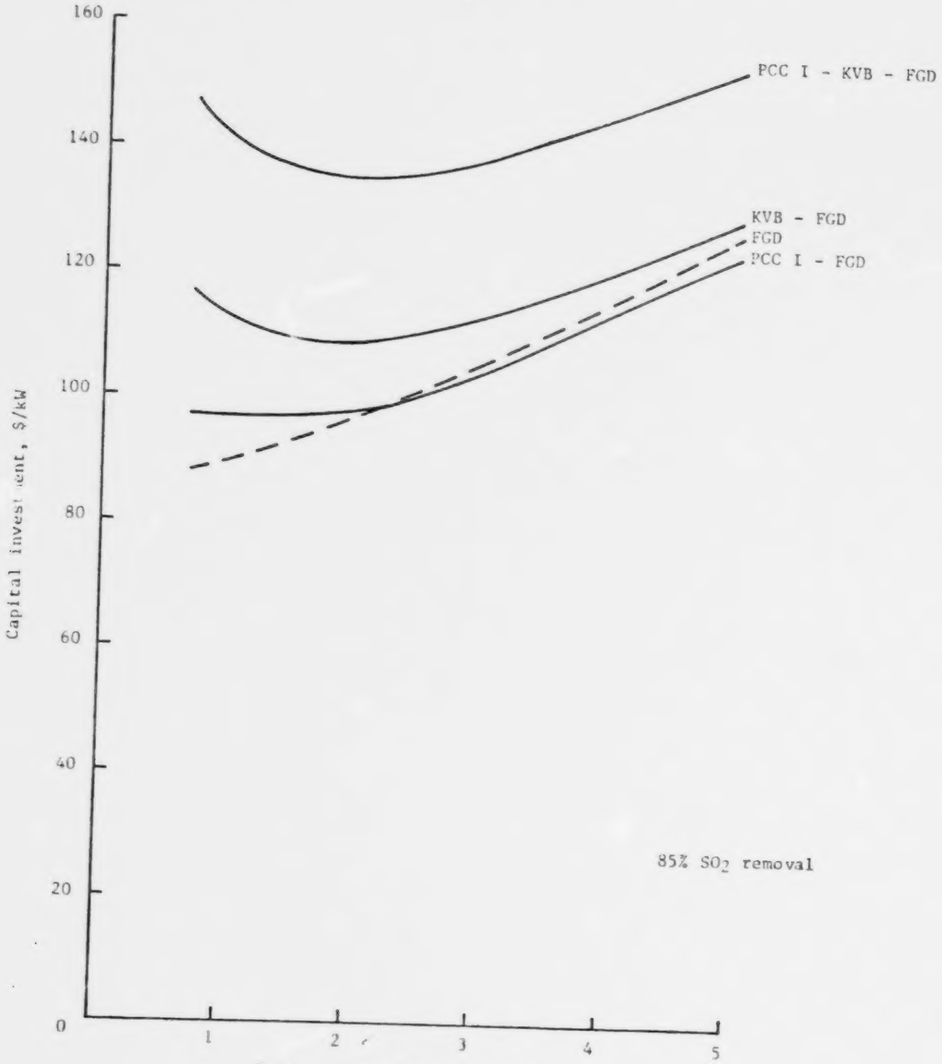

Figure 21. Capital investment to meet 85% reduction NSPS by coal cleaning and FGD.

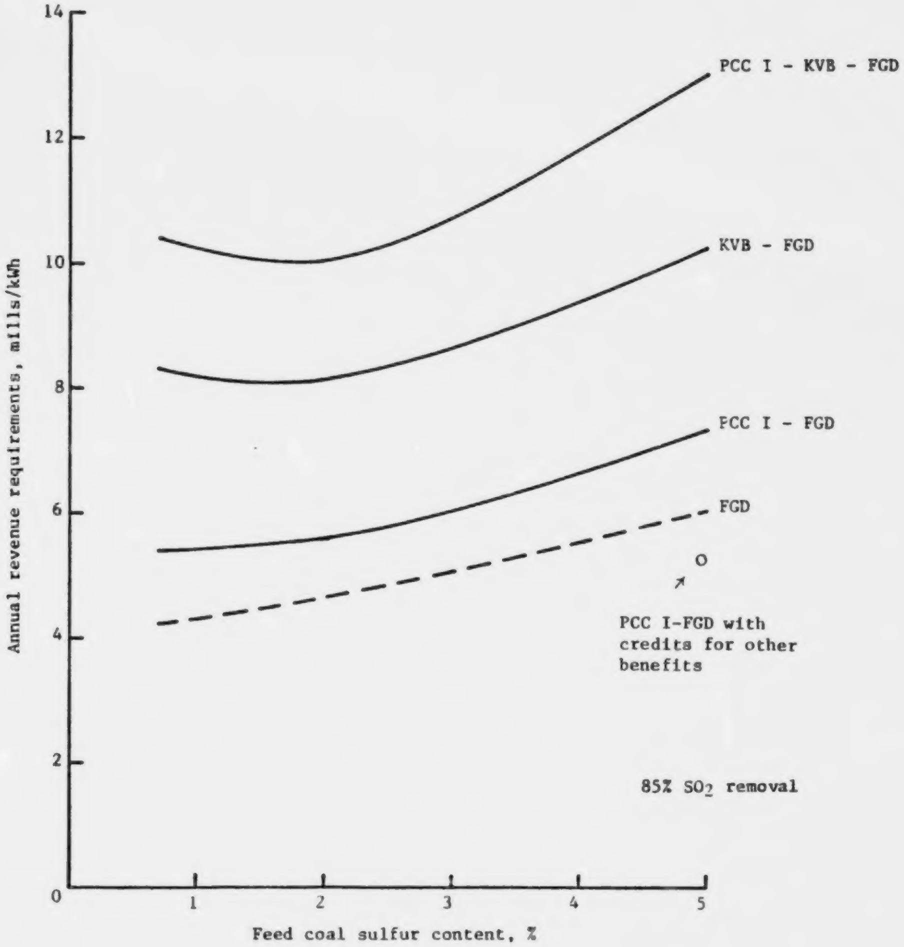

Figure 22. Annual revenue requirements to meet 85% reduction NSPS by coal cleaning and FGD.

The annual revenue requirements to meet the 85% reduction NSPS are higher for PCC I-FGD, KVB-FGD, or PCC I-KVB-FGD than for FGD alone. If the proposed floor of 0.2 lb SO_2/MBtu for the 85% reduction NSPS were higher, the PCC I-FGD process would become more competitive.

It should be emphasized that these cost comparisons between clean coal and FGD do not include certain other significant cost benefits of using clean coal. Recent papers (Cole, 1978; Phillips and Cole, 1979) showed penalties of up to $8 per ton for coals with combined sulfur and ash contents higher than 12.5% and up to 25%. This represents a potential net cost advantage of up to about 3 mills per kilowatthour for using clean coal.

Site-Specific Variables

Many site-specific variables affect the economics involved in determining the lowest cost method to meet emission standards. Some of these are discussed below.

Emission Standards--

Costs for coal cleaning, alone or in combination with FGD, will be most attractive for plants under higher SIP standards, less attractive for the 1.2 lb SO_2/MBtu emission limits, and least attractive for 85% reduction, as compared with costs for FGD alone. In other words, the economic advantage of coal cleaning, alone or with FGD, decreases as the allowable emission level is lowered. However, there may well be situations involving high-sulfur coal, limited FGD capability, and highly restrictive SIP standards, where FGD alone cannot meet the standard and coal cleaning with FGD provides an economic optimum.

Coal Properties--

Higher ratios of pyritic sulfur to organic sulfur will result in improved costs for most situations in which coal cleaning is used. In addition, better availability of the pyrite to removal by PCC, because of larger crystal size or more favorable particle distribution, will result in reduced costs for PCC processes. Sulfur content variability in the raw coal can also affect equipment size and reliability of operation for both coal cleaning and FGD. Higher heating value and lower inherent moisture of the raw coal will require that less coal be processed, a major factor in reducing equipment size and cost.

Plant Location--

In addition to geographical differences in construction and operating costs, the availability of barge, truck, or rail unloading facilities; raw or clean coal storage; service facilities; utilities; etc., can have major effects on costs. For example, the PCC and CCC plants evaluated in this study include a 15-day supply of cleaned coal (power plant usage basis) plus facilities for stacking, storage, and reclaim in addition to similar facilities for a 15-day supply of raw coal. If the coal-cleaning plant is located adjacent to the utility plant, the cleaned coal could be considered as part of the utility plant's normal 90- to 120-day stockpile. This would reduce both the installed capital and the working capital considerably.

Process Commercial Development--

Although the PCC processes studied are in a commercial stage of development, all of the CCC processes are relatively undeveloped. Future development work on these processes could substantially increase or decrease the projected costs. The significant reduction in sodium hydroxide usage recently reported by KVB for their process would make it more economically attractive. For example, a 50% reducion in sodium hydroxide usage would reduce the annual revenue requirement for the 5% sulfur coal by about 0.7 mill/kWh or by about 2.2 ¢/lb sulfur removed.

While the use of absorbents such as limestone to remove SO_2 during combustion has not been fully successful in the past, recent work reported by Battelle (Giammer et al., 1979) burning pellets made of finely ground limestone and coal showed a sulfur capture of about 75% in the boiler. Other work by Energy and Environmental Research Corporation (Zallen et al., 1979) has shown that sorbent utilization efficiency is sensitive to such conditions as temperature, stoichiometry, particle size, absorbent dispersion, fuel-air mixing characteristics, and combustion air staging. These tests show that it is necessary for the absorbent to be uniformly mixed with the combustion gases. With a 1:1 calcium to sulfur mole ratio, about 50% of the sulfur was captured by the absorbent for both the high- and low-sulfur coals.

After cleaning, the clean coal has a fine particle size and in some cases it must be pelletized for shipment or storage. These grinding and pelletizing or briquetting costs are included in the costs of the CCC processes studied. Grinding limestone and pelletizing it with the clean coal, using cement as a binder, would offer many process and cost advantages for both SO_2 control methods. For many coals this technique, if perfected, used with coals cleaned by the KVB process could even meet 85% SO_2 removal.

ECONOMIC BENEFITS AND PENALTIES OF USING CLEANED COAL

A recent objective of coal cleaning is compliance with SO_2 emission control regulations through removal of pollutant-forming constituents. In many instances, Federal or State standards are too stringent to be met by cleaning alone and the combined use of coal cleaning followed by FGD may be an alternative. Whether coal cleaning alone produces an environmentally acceptable product or whether it is only a step toward compliance, the user of cleaned coal must bear the costs incurred in the beneficiation process. In evaluating the economics associated with meeting SO_2 emission standards by coal cleaning it is necessary to assess the economic benefits and penalties for power plants using cleaned coal. Such economic effects could result from physical or chemical coal cleaning, but they are distinct from the need for emission control.

For a higher expenditure per ton of cleaned coal, the purchasing utility obtains a product which is of higher quality than run-of-mine coal. In addition to the primary benefit that cleaned coal is lower in pyritic, and perhaps organic, sulfur (depending upon the process), it is also usually lower in ash and higher in heating value, although often higher in surface moisture. Combustion of coal with these changed characteristics has numerous benefits and certain disadvantages to the utility user. The net effect is a significant credit which may be of sufficient magnitude to offset some, if not all, of the increased cost per ton of coal.

TRANSPORTATION COSTS

The cost of coal shipment is basically a function of rates which may vary considerably, depending on the mode of transportation and the distance the coal is transported. Coal beneficiation influences the cost of coal transportation by increasing the heating value of the coal and consequently reducing the quantity of coal necessary for supplying a given Btu requirement.

Coal movement to utilities may be an intricate process employing various modes of transportation. Rail shipment maintains preeminence over competing transportation methods, such as barge, truck, and slurry pipelines. Over one-half of all coal movement during 1975 was solely by rail; rail shipment alone and in conjunction with other shipping methods comprised almost two-thirds of total coal traffic (Gibbs and Hill, 1978). Because of trends in at least the near and intermediate future toward an even greater use of coal shipment by rail, it is important that rail transportation costs be used in illustrating the effect of coal beneficiation on transportation cost.

Using a general formula, accurate cost estimates for rail shipment for a specific situation are difficult to project because of the existence of wide variations in rate determination. Rate schedules are often negotiated individually, with such factors as mileage, region, and quantity of coal to be shipped serving to establish the applicable rate scheme. It is important, therefore, to be cognizant of the limitations imposed by the somewhat arbitrary pricing practices on the general equation for rate determination given below. The equation is based on analysis of unit train and carload rates for 680 U.S. origin - U.S. destination pairs in 1976 (Gibbs and Hill, 1978). It is adjusted to reflect 1982 conditions by applying a 7% per year inflation rate. The equation is as follows:

$$c = 197.75\ d^{-0.41}$$

where c is the freight cost in mills/ton-mile and d is the distance in miles.

For purposes of assessing the overall benefit in beneficiating coal, the following example with typical bases illustrates cost savings at 1982 cost projections. The transportation cost calculated from the equation with d = 600 miles is equal to 14.4 mills/ton-mile. Assuming a 10% increase in heating value, the transportation saving is 1.31 mills/ton-mile of uncleaned coal, resulting in a net savings of $0.78/ton for the entire 600 miles.

Shipment by unit trains is the least expensive means of rail transportation. To obtain these special low freight rates, these trains, made up of 100 to 170 coal cars, are designated for the exclusive delivery of coal to a specific plant. Because the majority of mining operations in the Appalachian region are small and do not ship the large quantities of coal necessary for unit train operation, this coal must often be shipped at a substantially higher rate. By centrally locating a cleaning plant capable of processing the output of a group of these mines, the quantity of product coal could easily be large enough to warrant negotiation of unit-train shipment, thereby further reducing transporation costs.

SAVINGS IN PAYMENT TO TRUST FUND

Provisions of the 1978 UMW contract require payment by the mine operator of $1.385 to the Pension and Benefit Trust Fund for each ton of coal shipped to a consumer. Because cleaned coal is lower in ash and higher in heating value, fewer tons of coal need be shipped to supply the required heat content demand of a power plant.

CRUSHING AND GRINDING COSTS

Coal crushing and grinding cost is defined by a number of factors. These include the magnitude of the size reduction required, the distinctive features of the size-reduction equipment, and certain properties of the feed coal. In particular, such coal characteristics as grindability, abrasiveness, moisture content, and heating value are primary determinants of crushing efficiency and cost. Coal cleaning significantly alters these coal characteristics, and hence size-reduction cost.

As a benefit, cleaning reduces mineral matter, which decreases coal hardness and facilitates crushing. Further, it increases the heating value of the coal, which produces dual effects: increased size-reduction capacity (in terms of Btu/hr) and reduced quantity of coal to be crushed. Detrimentally, cleaning may contribute additional surface moisture to coal, which renders pulverization more difficult.

By reducing the amount of harder impurities (e.g., rock, pyrite), cleaning will improve the grindability, resulting in a higher grindability index than that for the same coal in an uncleaned state. Correlation of pulverizer maintenance cost to coal grindability is difficult because of the influence of other variables, especially the presence of surface moisture. Detailed maintenance records for similar type pulverizers at four different TVA power plants indicate that a general correlation exists between the cost of maintaining pulverizers and coal grindability (Holmes, 1969). These records show that the pulverizer maintenance costs increase linearly until the sum of the ash and sulfur in the coal is about 17.5% and then at a considerably higher rate as this sum increases above 17.5%.

Generally, the most prominent and easily quantified effect of cleaning on pulverization cost is the effect of increased heating value of the coal. Because cleaned coal has a higher heating value than uncleaned coal, less has to be ground to supply a given Btu requirement. It is estimated that at current conditions it costs $0.50 to grind one ton of coal, including both operation and maintenance costs (Gibbs and Hill, 1978). The cost savings relationship (per ton) may be calculated as follows:

$$\text{Cost savings} = (\$0.50)(x)/(1 + x)$$

where x is the decimal increase in heating value.

A further benefit of the increased heating value of the coal is the increased Btu capacity of the pulverizer. The percentage increase in Btu capacity corresponds approximately to the percentage increase in heating value.

As mentioned earlier, coal beneficiation processes may result in an undesirable increase in surface moisture of the product coal. High surface moisture can cause slippage of the grinding elements and produce agglomeration of fines in the pulverizer. Consequently, mill capacity is reduced because the fines are not removed as quickly as they are produced. Generally, the influence of moisture on mill capacity varies between types of mills but it intensifies as surface moisture increases. Surface moisture in excess of 3% is considered detrimental to grinding capacity (Murphy et al., 1977).

The coal-cleaning processes also generally have a product that is much smaller in particle size than the run-of-mine coal so that a large amount of the required size reduction has already been done. Costs for this size reduction are included in the cleaning costs.

It is apparent from the preceding discussion that assessment of the overall effect of coal beneficiation on pulverization cost involves consideration of a number of cause-and-effect relationships. The effects of cleaning on coal heating value, surface moisture, grindability, and abrasiveness must be evaluated for their influence on pulverizer capacity and operational and maintenance costs. In a given circumstance any or all of these may be significant. The net result is an economic benefit which is diminished to varying degrees by the effects of added surface moisture.

BOILER CAPACITY AND FURNACE VOLUME

By increasing the heating value of the coal, coal cleaning contributes to an increased capacity for the coal feed system to the boiler (in terms of Btu/hr) and the boiler ash removal system. Because boilers are generally built with a 15% to 22% coal feed system overdesign (Tufte et al., 1976), such limitations do not normally limit boiler capacity. However, boiler capacity derating has resulted on occasions when emission regulations have been met by the substitution of low-sulfur western coal in boilers designed for high-sulfur eastern coal. The use of cleaned coal instead of low-sulfur, low-heating-value coal could restore this capacity loss.

The size of the furnace is determined to a great extent by the slagging characteristics of the ash. By reducing the slagging tendency of the coal, coal cleaning could also permit the design of furnaces with higher heat transfer rates and correspondingly smaller furnace volume.

BOILER PERFORMANCE AND CAPACITY FACTOR OF THE GENERATING FACILITY

Some of the most important considerations in the design of a boiler are the characteristics of a coal and its ash. Reliable boiler operation is dependent upon the application of design techniques to minimize slagging, fouling, and corrosion problems. These problems in a large measure directly affect boiler availability. Fireside problems are responsible for many coal-fired operational difficulties resulting in both forced and scheduled outages. They significantly affect the cost of boiler operation and maintenance as well as the capacity factor and the availability of the generating facility. By improving coal characteristics contributing to these problems, coal cleaning can favorably affect the economical use of coal. Coal characteristics vary widely, however, and different methods of cleaning can have diverse effects on the properties of the cleaned coal. For this reason the effects of coal cleaning on boiler operation will, in a given circumstance, be dependent upon both the cleaning method used and the original characteristics of the coal.

Although differences of opinion exist as to the relative importance of slagging, fouling, and corrosion, it is agreed that slagging can be an extremely serious problem in pulverized-coal-fired boilers. Slag formation on furnace walls, particularly in the vicinity of the burners, has been responsible for frequent boiler outages and reduced load operation of boilers (Anson, 1977).

Coal beneficiation may significantly reduce slagging tendency because lowering the amount of pyrite in the coal reduces the amount of iron oxides produced (Gibbs and Hill, 1978).

Another problem encountered in the operation of pulverized-coal-fired boilers is ash fouling of heat transfer surfaces. The areas primarily affected by fouling are superheaters and reheaters where temperatures can permit condensation of ash elements volatilized in the burning process. To a large extent, ash fouling can be controlled, but not eliminated, by proper boiler design. However, because of deterioration or change in fuel supplies, many utilities have been forced to operate boilers with coals having ash different in quantity and composition from those coals for which the boiler was designed. The most serious problems resulting from fouling are interference with heat transfer, plugging of gas passages, and establishment of conditions conducive to tube corrosion beneath the deposits.

Further research is needed to correlate fouling tendency and the minerals most directly responsible for its occurrence. Although it may prove impossible to prepare coals specifically lower in content of those substances causing fouling, evidence exists that cleaning may diminish the extent of fouling by reducing the net quantity of ash entering the boiler.

Corrosion of boiler tubes is a third fuel-related problem in boiler operation. Boiler tube failures are perhaps the most serious plant problem in electric power generation (Anson, 1977). Forced outage rates due to tube failure are commonly in the range of 5% to 10% with some forced outage rates from this cause as high as 15%. More than 90% of boiler tube failures result in forced outages. Typically, an outage caused by tube failure has a duration of 3 to 6 days because of the need to cool and drain the boiler for access.

By reducing the slagging and fouling tendencies of coal, beneficiation may indirectly diminish corrosion by minimizing conditions favorable to corrosive reactions. Coal cleaning may have a more direct affect by removing substances important in the corrosion mechanism, principally the alkali metals and sulfur. Sulfur oxidizes and reacts with moisture to form sulfuric acid which corrodes metal surfaces. Further, the reaction of sulfurous gases with ash deposited on the tubes produces complex sulfate compounds which are highly corrosive. Investigations show that coal cleaning may produce a coal substantially less corrosive than the raw coal (Holmes, 1969).

The cost of operating and maintaining boilers is influenced by coal quality, as evidenced by the experience of two TVA steam plants (Holmes, 1969) provided with virtually identical equipment. Neither of these plants, which were placed in operation in the middle 1950's, burned cleaned coal but they burned coal of different quality because of different sources of the coal. The average proximate analysis of the coal burned at these two plants is shown in Table 23.

TABLE 23. COAL PROPERTIES AT TWO SIMILAR TVA POWER PLANTS

	Moisture, %	Volatile matter, %	Fixed carbon, %	Ash, %	S, %	Heating value, Btu/lb
Plant A	4.9	32.4	52.1	10.8	1.0	12,680
Plant B	5.1	33.8	47.7	13.4	2.7	12,053

The relative boiler maintenance cost per ton of coal burned is nearly two times as high for Plant B as for Plant A. The sum of maintenance cost for soot blowers and burners is more than twice as high for Plant B as for Plant A. This comparison indicates the effect of coal quality on maintenance costs and reveals an important benefit which may be obtained by using cleaned coal.

Perhaps the most significant single advantage in the use of cleaned coal followed by FGD is the increase in capacity factor which may result from the use of coal with improved characteristics. Capacity factor is defined as the total generation in megawatts per hour divided by the product of period hours times the unit capacity. Although capacity factor reflects more than the performance of the boiler itself, it includes boiler performance within its scope. An increase in capacity factor from 45% to 56% was reported by TVA (Cole, 1978) when using three Western Kentucky coals after cleaning. The effect of the increase in capacity factor is an increase in total generation and an ensuing decrease in total generation cost.

ASH-HANDLING COSTS AT THE UTILITY

Coal beneficiation reduces ash-handling costs (Picklesimer, 1978) in two closely related ways: firstly, coal cleaning lowers the ash content of the coal to be burned; and secondly, by diminishing ash content coal cleaning decreases the quantity of coal needed to supply a given Btu requirement. The percentage reduction potentially obtained is expressed in the following equation:

$$\% \text{ reduction in ash-handling costs} = 100\ [A_1 - (A_2 \times W)]/A_1$$

where:

A_1 = % of ash in uncleaned coal (expressed as a decimal)

A_2 = % of ash in cleaned coal (expressed as a decimal)

W = weight of coal in pounds which is needed to supply the number of Btu in one pound of uncleaned coal

Simplification provides the following:

$$\% \text{ reduction in ash-handling costs} = 100\ [1 - (A_2 \times W)/A_1]$$

The percentage reduction in ash-handling costs may be substantial, as exemplified by the cleaning of coal from Peabody No. 9 deep mine before use at the TVA Paradise Steam Plant (TVA, 1977). Raw coal containing 14.93% ash is rated at 12,265 Btu/lb heating value. Cleaning results in a product with the ash content lowered to 8.59% and the heating value increased to 13,320 Btu/lb. Substituting these data in the above equation gave a 47% reduction of ash handled.

Savings due to ash removal may also be obtained in the expenditures to maintain ash-handling systems. The two TVA plants placed in operation during the middle 1950's with virtually identical equipment but using coals of different quality (Table 23) were compared for the period from startup through 1969. Maintenance costs on bottom ash hoppers for the plant burning coal with higher ash and sulfur contents were approximately 65% higher per ton of coal. Approximately 40% more money was spent for maintenance on fly ash collectors for the coal with higher ash and sulfur contents.

IMPROVED FGD OPERATION AND REDUCTION IN BOILER DOWNTIME

Boilers fitted with FGD equipment have an inherent amount of time in which they cannot operate because the FGD systems are not operable. During this time power must often be purchased to replace power which would otherwise have been produced by the boiler. As FGD availability is increased, savings occur since produced power is normally cheaper than purchased power. Assuming 85% availability of each individual scrubbing system and assuming a 500-MW plant is equipped with four scrubbers and one redundant scrubber, the predicted boiler downtime resulting from FGD downtime is 0.8%. It is not possible to quantify the reduction in FGD downtime which may be obtained by burning coal which has been processed to remove sulfur and ash. It is, however, pertinent to note that some FGD systems have experienced markedly better operation, in addition to a corresponding reduction in maintenance requirements, when low-sulfur coal was substituted for the high-sulfur coal for which the FGD units were designed (Kennedy and Tomlinson, 1978). The Kansas Power and Light Company's Lawrence No. 4 installation shifted to low-sulfur coal in 1974 which reduced scrubbing requirements and increased scrubber availability. At the Will County Power Plant limestone scrubbing system, operated by Commonwealth Edison, operating problems were reduced by burning low-sulfur coal. Scrubber problems increased during a test run in which high-sulfur coal was burned. The Hawthorne No. 4 FGD system was plagued by plugging, scaling, and erosion, resulting in low availability of the system. Improved system dependability was obtained by a switch to low-sulfur coal and certain modifications to the unit.

In view of these and other examples, it is evident that operating difficulties with FGD processes increase with high-sulfur coal. Several installations have switched from high- to low-sulfur coal for this reason. Although no detailed statistical basis exists for quantifying the resulting decrease in FGD downtime which occurs when coal of lower sulfur content is burned, it is reasonable to conclude that an increase in system availability is an obviously correlated phenomenon.

ESP SIZE AND COST

The removal of fly ash from flue gas is usually accomplished by ESP units, placed immediately behind the furnace air preheaters. The resistivity of the ash is the major factor in determining the collection area of the ESP. Resistivity is determined by many factors, including ash composition and SO_3 level in the gas. The effects of coal cleaning on ESP design will have to be assessed on an individual basis.

The cost associated with cleaning particulates from flue gas by ESP is partly a function of sulfur concentration. Removal of fly ash from cleaned coal with lower sulfur level will be more difficult if conventional ESP units are used. Other particulate removal systems which are not dependent on sulfur concentration may be less expensive when burning cleaned coal. Other such systems are hot side ESP (operating at 700°F), bag filters, and pulsed ESP.

The ash and sulfur contents of coal are major influences in ESP design. In some cases the reduction in ash more than offsets the increase in resistivity caused by sulfur reduction. The ESP cost increases dramatically for coal sulfur levels below 2%.

FGD SYSTEMS CAPITAL AND OPERATING COSTS

The sulfur content of coal is an important factor in the design and cost of FGD systems. FGD systems on boilers burning high-sulfur coal cost considerably more than systems designed for identical boilers burning lower sulfur coal. This cost increase for FGD systems for boilers burning higher sulfur coal is a result of the necessity for larger absorbent preparation facilities (receiving equipment, storage, grinding, and slaking) and the increase in system size required for sludge disposal as well as the size of the scrubbing system itself. Coal cleaning should result in a corresponding decrease in the cost of both absorbent preparation facilities and sludge disposal. Table 24 shows projected investment costs and revenue requirements for FGD systems on new coal-fired power units for coals with different sulfur contents.

TABLE 24. LIMESTONE SLURRY FGD COSTS

	% sulfur in coal			
	0.7	2.0	3.5	5.0
Total capital investment, 10^3\$	176,642	194,336	221,298	247,380
Annual revenue requirements, 10^3\$/yr	46,239	50,854	57,795	64,218

Basis
2000-MW new power plant, Midwest location, represents project beginning mid-1979, ending mid-1982. Annual revenue requirements based on end-1982 costs, 25% scrubber redundancy, 9500 Btu/kWh heat rate, 5500 hr/yr operating time at full capacity. Eighty-five percent sulfur removal.

REDUCED DERATING OF POWER OUTPUT FOR FGD OPERATION

The derating of the power output as a result of the operation of FGD equipment has two principle causes: (1) energy is expended in the operation of the equipment and (2) energy production is lost or reduced as a result of FGD downtime. Coal cleaning lowers derating of power output to degrees which vary depending on circumstances dictated by each individual situation. Nevertheless, it is possible to draw conclusions which apply generally by observation of specific cases.

Cleaning coal to reduce sulfur content decreases energy consumption by the FGD equipment. In the limestone slurry process, the energy-intensive primary equipment such as the absorber and induced-draft fan will not consume significantly less power when burning lower sulfur coal since gas volume is essentially constant. However, the electricity for the processing and handling circuit for the slurry from the absorber will be reduced as a direct result of decreased sulfur level. The following tabulation illustrates electricity requirements and projected 1982 operating costs of a limestone slurry FGD system installed on a new power unit and effecting 90% sulfur removal. Power requirements increase as coal with higher sulfur is burned as fuel.

% S of coal	kWh required for operation	1982 \$/kWh	1982 cost for electricity, \$
2.0	46,797,620	0.039	1,825,000
3.5	49,480,400	0.039	1,930,000
5.0	51,545,970	0.039	2,010,000

The energy requirement of the limestone process is about 3% to 4% of the input energy to the boiler. The lime slurry process energy requirement is slightly higher at an estimated 5%. Equivalent process energy requirements for other SO_2 removal processes range as high as 10% to 11% of the input energy to the boiler (Kennedy and Tomlinson, 1978).

SAVINGS IN STACK GAS REHEAT COSTS

To ensure proper dispersion of flue gases in the atmosphere and reduce stack corrosion, flue gases from the absorber in wet FGD processes must be heated to about 175°F before entering the stack. It is possible to save energy if some gas is allowed to bypass the absorber and mix with the cooler gas before entering the stack. The amount of gas that can be allowed to bypass the absorber is dependent on the SO_2 content of the gas.

Considerable savings on reheat can be realized if cleaned coal is burned in the boiler. Up to 70% of the total flue gas can be scrubbed and returned to 175°F without the use of steam reheaters. The savings in the reheat portion of FGD will be proportional to the amount of gas that is allowed to bypass the absorber.

Some utilities have tried to operate FGD systems without a reheater (i.e., Conesville and Cane Run 4) and have experienced severe stack corrosion due to acid reflux in the stack (Kennedy and Tomlinson, 1978). These companies have been forced to resort to reheaters after experiencing these problems. The actual cost reduction for flue gas reheating is dependent on the overall sulfur reduction in the coal, which determines the amount of flue gas that can be bypassed.

SURFACE MOISTURE ADDED TO COAL BY CLEANING PROCESSES

Among the undesirable constituents of coal are varying quantities of water occurring both as internal and surface moisture. The presence of water in coal has two primary adverse effects on the economical use of coal: moisture results in Btu loss since it must be heated and vaporized during the combustion process, and moisture increases transportation costs by contributing additional weight to the coal. To the extent that cleaning processes increase the surface moisture of coal they increase these effects.

On a net basis, typical boiler conditions require the vaporization and heating of water in the coal to 300°F, the temperature of the flue gas leaving the air heater. This process consumes about 1150 Btu for each pound of water. Consequently, if 111 pounds of water is added to 1,000 pounds of surface-dry coal having a total heating value of 12,000,000 Btu, the resulting product is 1,111 pounds of coal containing 10.0% surface moisture and a total heating value of approximately 11,877,000 Btu. In this example a total of 123,000 Btu is spent in the heating and vaporization of water during the burning process. In general, a 10% increase in total moisture reduces the net heating value of the coal by approximately 1%.

The extent to which increases in moisture increase coal transportation costs has two basic determinants, both of which are related to the Btu content per pound of coal. It is essential to recognize not only the added weight of the moisture but also the Btu loss associated with the necessity for evaporization and heating of the water during combustion. If moisture adds 11.1% to the weight of the coal as described in the preceding example, a corresponding 11.1% increase in cost of transporting the coal ensues. Further, since the addition of water actually reduces the net heating value of the coal, it imposes an additional cost burden on transportation expenditures.

CONCLUSIONS AND RECOMMENDATIONS

1. The three PCC processes remove 29% to 39% of the total sulfur of the bituminous coals. The CCC processes have significantly higher sulfur removals; KVB is the highest with 73% to 76% removal. Sulfur removal of the subbituminous coal is significantly lower for all processes because of the high ratio of organic sulfur to pyritic sulfur.

2. PCC is a commercial, cost-effective method of meeting the pre-1978 1.2 lb SO_2/MBtu NSPS for coals with sulfur levels below about 1.2%. Older utility plants that are requried to meet less stringent SIP's or industrial boilers can utilize coals with even higher sulfur levels.

3. PCC plus partial scrubbing with limestone FGD is generally cost effective in meeting the pre-1978 1.2 lb SO_2/MBtu NSPS, as compared with FGD alone, for feed coals with sulfur contents below about 3%. Above this sulfur level, the PCC plus FGD method generally has lower capital investment but slightly higher annual revenue requirements. When other benefits of using cleaned coal are credited, PCC plus FGD should also be competitive at the higher sulfur levels.

4. Although PCC technology is simple in concept, its application is complex and a detailed study of site-specific conditions is necessary in order to forecast costs and benefits.

5. Coals with a sulfur content up to about 3% can be cleaned with the KVB process to meet the pre-1978 1.2 lb SO_2/MBtu NSPS.

6. The CCC processes studied are generally higher in both capital investments and annual revenue requirements than the PCC processes. The Kennecott process is most expensive and the KVB process the least expensive of the CCC processes studied.

7. Coal cleaning plus partial scrubbing with limestone FGD is generally less cost effective in meeting 85% SO_2 removal than limestone FGD alone. KVB plus FGD and PCC I plus FGD have about the same capital investment as FGD for sulfur levels above about 3%, but have higher annual revenue requirements. Credit for the other benefits of using cleaned coal can make PCC I plus FGD competitive at the higher sulfur levels.

8. The KVB process or KVB plus partial FGD scrubbing generally have lower capital investment and higher annual revenue requirements

(mills/kWh) than FGD alone. Recent work by KVB to improve the sodium hydroxide usage of this process could make a significant improvement in annual revenue requirements. All CCC processes require additional process development before costs can be more accurately calculated.

9. The KVB process is the most energy efficient process of the PCC and CCC processes studied. The coal lost in the refuse is the major energy loss or usage for the PCC processes and represents about half of the total annual revenue requirements.

10. The use of clean coal has many additional economic benefits and a few penalties. The net result could be a cost reduction which would substantially reduce the costs of coal cleaning. Recent work based on limited data shows that these benefits could have a net cost advantage of up to about 3 mills/kWh. Additional work should be done to identify and quantify these benefits.

11. Coal cleaning or coal cleaning plus FGD may have even more application for small peaking load utility boilers or for industrial boilers than for large base load utility boilers.

12. A potentially advantageous SO_2 emission control approach that should be investigated further is pelletization of the already finely ground clean coal with limestone for further sulfur removal during combustion. This could expand the potential for economic sulfur removal by coal cleaning.

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GLOSSARY

Ash: The residue resulting from the complete combustion of coal conducted according to specified test procedures. Colloquially, ash often denotes the ash-producing minerals, clays, and shale which occur in coal.

Bituminous coal (also see Coal): A broad category of agglomerating black soft coal with a calorific value of 11,000 to 16,000 Btu/lb when moist but free of mineral matter.

Chemical coal cleaning: A process in which sulfur- or ash-producing compounds, or both, are separated from coal by changing the chemical nature of the sulfur or ash materials but without changing the pure-coal matrix.

Coal: A naturally occurring brownish black to black combustible solid formed by the partial decomposition of vegetation from geologic periods of about 1 to 300 million years ago. Successively with time, the decomposition produced peat, lignite, subbituminous coal, midwestern bituminous coal, eastern bituminous coal, anthracite coal, and graphite. In general, the moisture and volatile matter decrease while the fixed carbon and calorific value tend to increase in that order. Coals are constituted from C, H, O, and N, and they contain widely varying amounts of clay and mineral impurities.

Coal beneficiation: The upgrading of coal to higher purity and normally to higher calorific value by the removal of impurities.

Coal cleaning: A process in which sulfur or ash materials are removed from coal by physical or chemical treatment.

Coal conversion: A process for removing sulfur- or ash-producing materials, or both, from coal and for converting the coal to a fuel of different physical and chemical nature.

Coal preparation: A broad term referring to crushing, sizing, coal cleaning, drying, or other treatment needed to meet the market specifications for the coal.

Coal washing: A physical coal-cleaning process in which pyrite, ash materials, and some fine coal are separated from a bed of raw coal in a coal washing machine by alternately flooding and draining the bed or by some other arrangement of hydraulic washing.

Concentrating table: A relatively flat, riffled, oscillating table for the hydraulic separation of heavy impurities, such as pyrite and ash, from coal. A mixture of moderately fine coal and water is fed to upper right section of the table which slopes slightly downward from the feed location. As water and light particles overflow the riffles toward the coal discharge, heavy pyrite particles are retained by the riffles and oscillated slightly uphill to a discharge at the left end of the table. Additional "dressing water" is added along the upper edge of the table to facilitate an even flow across the table.

Dense medium (also called heavy medium): A liquid, such as a halogenated solvent, used for precise float-sink test separations of coal fractions over the specific gravity range of about 1.3 to 1.7 or 1.9. In commercial coal cleaning, the dense medium normally is a suspension of fine magnetite in water for use at a definite specific gravity within the range of about 1.35 to 1.7.

Dense-medium cyclone (DM cyclone, heavy-medium cyclone, HM cyclone): A high-efficiency concentrating cyclone in which liberated pyrite and ash are separated from coal by the action of centrifugal force. The cyclone has a relatively short cylindrical upper section and a relatively long conical lower section, the whole installed at a slight inclination to horizontal. A mixture of intermediate-sized coal and dense medium of controlled specific gravity is fed tangentially to the lower section of the cylinder and a lighter fraction of clean coal and medium emerges tangentially from the upper section of the cylinder. A mixture of heavier impurities leaves the cyclone through the apex of the cone.

Dense-medium vessel (DM vessel, heavy-medium vessel, HM vessel): A high-efficiency gravity-type separator with a trough-, conical-, or other-shaped vessel filled with a DM fluid of controlled specific gravity. Coarse- or medium-sized coal is gently immersed in the bath where lighter, cleaner coal particles float and overflow the vessel, usually with mechanical assistance. Heavier refuse particles are removed from the bottom of the vessel by flight conveyor, elevator, or other means.

Float-sink: The partial separation of coal and its impurities by immersion of the raw coal in a DM whose specific gravity is between that of the lighter coal and the heavier impurities. The immersion may be in a static bath, such as a laboratory vessel or a commercial DM vessel, or under dynamic conditions such as in a commercial DM cyclone. The completeness of separation is limited mainly by the degree of dissemination of impurities and hence by the degree of their liberation at the particle size being used.

Froth flotation: In coal cleaning, a process by which pyrite and some other impurities can be separated from very fine coal in an aerated aqueous suspension. Under the influence of surface-active flotation reagents, pyrite particles attach to rising air bubbles while the coal particles remain depressed. Alternatively, pyrite may be depressed while coal is floated. Floated material is removed from the flotation tank in the overflowing froth of air bubbles.

Inherent moisture: See Internal moisture.

Internal moisture: The moisture contained within a coal particle. It is not normally removable by air drying or by mechanical or thermal dewatering using regular commercial equipment. It tends to be characteristic of the rank of the coal.

Lignite (also see Coal); A nonagglomerating brown to brownish-black coal with 30% to 50% internal moisture and less than 9300 Btu/lb when moist but free of mineral matter.

Middling: A product of intermediate purity. In this report the middling coal is purer than the raw coal but less pure than the ultraclean coal.

Moisture-free: Having zero surface moisture and zero internal moisture.

Organic sulfur: Sulfur which is chemically combined with pure coal.

Physical coal cleaning: A process in which inorganic sulfur- and ash-producing compounds are separated from coal by physical methods without changing the chemical nature of the sulfur and ash materials and without changing the pure-coal matrix.

Pulp density: The proportionate weight, often as a percentage, of solids in a mixture of solids and water.

Pure coal: A hypothetically pure coal which contains no sulfur, ash, or other impurities.

Pyritic sulfur: Sulfur in the form of the FeS_2 minerals, pyrite or marcasite, which is physically mixed with or physically attached to, but not chemically combined with, the pure coal.

Raw coal: In this report, the feed coal to a coal-cleaning plant. Its only prior preparation after mining has been passage through a rotary breaker (a rotating horizontal perforated cylinder) for the removal of debris and material which resists tumble crushing to 3-inch top size. A magnet in the conveyor system removes tramp iron.

Refuse: The waste byproduct consisting of pyrite and other mineral impurities, clay, shale, and impure coal which are removed by coal cleaning.

Slurry: A mixture of water and solids.

Subbituminous coal (also see Coal): A nonagglomerating near black coal with up to 30% internal moisture and with a calorific value of 8,300 to 11,000 Btu/lb when moist but free of mineral matter.

Sulfate sulfur: Sulfur in the form of usually soluble inorganic sulfates which result from the oxidation of pyrite in coal.

Surface moisture: The moisture on the surface of a coal particle. It is removable to an equilibrium level by the evaporation provided by thermal drying or by air drying. Its reduction by mechanical dewatering depends on the fineness of the coal as well as on the equipment characteristics.

Total moisture: Including both surface and internal moisture.

Washability data: Tabular results of laboratory determinations of composition and calorific value of coal and refuse fractions which float or sink at successively higher specific gravities.

APPENDIX A

MATERIAL BALANCES AND EQUIPMENT LISTS

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TABLE A-1. PCC I PROCESS

(CLEANING AT COARSE, INTERMEDIATE, AND FINE SIZES)

MATERIAL BALANCE - BASE CASE (5% S COAL)

TABLE A-1 (continued)

	Stream No.	1	2	3	4	5	6	7
	Description	Raw coal to sizing (3 in. x 0)	Coal to crusher (3 in.x1-1/4 in.)	Coal from raw coal screen (1-1/4in.x3/8in.)	Coal from raw coal screen (3/8 in. x 0)	Coal to DM vessel (2 in.x 3/8 in.)	Coal to fines screens (3/8 in. x 0)	Oversize from fines screens (3/8 in.x 28 m)
1	Total stream, tons/hr	861.7	104.5	333.5	643.3	328.6	735.0	509.1
2								
3	Stream components, tons/hr							
4	Coal, bone-dry	806.6	94.8	292.9	418.9	298.1	508.5	442.2
5	Water, total	55.1	9.7	30.0	224.4	30.5	226.5	66.9
6								
7								
8	Gal/min						2,393.6	
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
32								
33	Ash, tons/hr	134.7	15.8	48.9	70.0	49.8	84.9	73.8
34	Pyritic S, tons/hr	27.0	3.2	9.8	14.0	10.0	17.0	14.8
35	Total S, tons/hr	40.3	4.7	14.6	21.0	14.9	25.4	22.1
36								
37	Btu/lb, bone-dry	12,000	12,000	12,000	12,000	12,000	12,000	12,000
38								
39								
40								

(continued)

(continued)

TABLE A-1 (continued)

	8	9	10	11
	Undersize from fines screen (28 m x 0)	Clean coal from DM vessel centrifuge (2 in.x 3/8 in.)	Refuse from DM vessel rinse screen (2 in.x 3/8 in.)	Feed to DM cyclones (3/8 in.x 28 m)
1	357.6	268.3	49.6	1,738.9[a]
2				
3				
4	66.3	253.1	45.0	442.2
5	291.3	15.2	4.6	1,296.7
6				
7				
8				7,258.1
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33	11.1	28.2	21.6	73.8
34	2.2	5.6	4.4	14.8
35	3.3	9.8	5.1	22.1
36				
37	12,000	12,800		12,000
38				
39				
40				

a. Excluding 1,010.3 tons/hr of magnetite.

(continued)

TABLE A-1 (continued)

	12	13	14	15
	Clean coal from DM cyclone centrifuge (3/8 in. x 28 m)	Refuse from DM cyclone centrifuge (3/8 in.x 28 m)	Feed to froth flotation (28 m x 0)	Clean coal from froth flotation filter (28 m x 0)
1	404.7	78.8	687.0	76.8
2				
3				
4	370.1	72.1	66.3	55.6
5	34.6	6.7	620.7	21.2
6				
7				
8			2,676.8	
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33	35.7	38.1	11.1	4.7
34	7.2	7.6	2.2	0.9
35	13.3	8.8	3.3	1.9
36				
37	13,000		12,000	13,200
38				
39				
40				

(continued)

TABLE A-1 (continued)

	16	17	18	19
	Refuse to flotation thickener (28 m x 0)	Refuse from flotation filter (28 m x 0)	Clarified water	Makeup water
1	585.0	14.8	570.2	31.4
2				
3				
4	10.7	10.7		
5	574.3	4.1	570.2	31.4
6				
7				
8	2,327.3		2,280.8	125.6
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33	6.4	6.4		
34	1.3	1.3		
35	1.4	1.4		
36				
37				
38				
39				
40				

(continued)

TABLE A-1 (continued)

	20	21		
	Refuse to disposal site	Clean coal to stockpile		
1	143.2	749.8		
2				
3				
4	127.8	678.8		
5	15.4	71.0		
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33	66.1	68.6		
34	13.3	13.7		
35	15.4	24.9		
36				
37		13,000		
38				
39				
40				

TABLE A-2. PCC I PROCESS

(CLEANING AT COARSE, INTERMEDIATE, AND FINE SIZES)

EQUIPMENT LIST - BASE CASE (5% S COAL)

NOTE: Coal tonnages are listed as bone-dry coal excluding the internal moisture of 3.5% in the base-case coal. However, equipment sizes include the handling of internal and of surface moisture.

Area 1--Coal Receiving and Storage

Item	No.	Description
1. Unloading conveyors for conveying 1,600 tons/hr, 3 inch x 0 raw coal from unloading station to stockpiles	2	Inclined conveyor, 500 feet long, with 1 fixed tripper, 48-inch-wide belt, carbon steel, with tramp-iron magnet; 125 hp
2. Stacking conveyors for distributing coal along the tops of 2 parallel and adjacent wedge-shaped open piles, each of 175,000 tons	2	Elevated horizontal conveyor, 1,000 feet long with 1 traveling tripper, 48-inch-wide belt, telescoping chute, carbon steel; 40 hp
3. Hoppers for reclaiming 807 tons/hr of 3 inch x 0 raw coal from stockpiles	20	Reclaiming hopper with 14 feet x 14 feet top opening, 3-1/2-feet-deep pyramid, and 24 inch x 24 inch bottom opening, carbon steel
4. Pan feeders for withdrawing 807 tons/hr of 3 inch x 0 raw coal from reclaiming hoppers.	20	Vibratory pan feeder with 26 inch wide x 48 inch long pan, carbon steel; 1.5 hp vibrator
5. Collecting conveyors for 807 tons/hr of 3 inch x 0 raw coal from pan feeders	2	Horizontal conveyor, 1,000 feet long with 36-inch wide belt, carbon steel; 35 hp
6. Tunnels for collecting conveyors	2	Steel-reinforced concrete tunnel 8 feet wide x 6 feet deep x 1,000 feet long
7. Tunnel sump pump	2 + 1 spare	Centrifugal pump, 60 gpm, 30-feet head, carbon steel; 1 hp

(continued)

TABLE A-2 (continued)

Item	No.	Description
8. Transfer conveyor	1	Horizontal conveyor, 320 feet long with 36-inch-wide belt, carbon steel; 10 hp
9. Tunnel for transfer conveyor	1	Steel-reinforced concrete tunnel, 7 feet wide x 6 feet deep x 320 feet long
10. Tunnel sump pump	1 + 1 spare	Centrifugal pump, 60 gpm, 30-feet head, carbon steel; 1 hp
11. Delivery conveyor for 807 tons/hr of 3 inch x 0 raw coal to raw coal sizing area	1	Inclined conveyor, enclosed 600 feet long, 36-inch-wide belt, with belt scale, carbon steel; 75 hp
12. Automatic sampling of coal from stockpile to raw coal sizing area	1	Automatic sampler of plate or similar type conforming with ASTM sampling requirements, primary sampling from 403 tons/hr of 3 inch x 0 coal from delivery conveyors
13. Bulldozer for servicing raw coal storage piles	1	Diesel bulldozer; 100 hp

Area 2--Raw Coal Sizing

Item	No.	Description
1. Raw coal screens for sizing 807 tons/hr of 3 inch x 0 coal to 95 tons/hr of 3 inch x 1-1/4 inch, 293 tons/hr of 1-1/4 inch x 3/8 inch, and 419 tons/hr of 3/8 inch x 0	4	Double-deck horizontal vibrating screen, 6 feet wide x 16 feet long, low-noise suspension, standard positioning of water sprays for both decks, stainless steel flanged plates for screening at 1-1/4 inch and at 3/8 inch, carbon steel body; 15 hp
2. Crusher for reducing 95 tons/hr of 3 inch x 1-1/4 inch coal to 2 inch x 0	1	Single roll crusher with 24 inch x 24 inch roll and stationary breaker plate, materials of construction suited to secondary crushing of medium-hard bituminous coal; 25 hp

(continued)

TABLE A-2 (continued)

Item	No.	Description
3. Pre-wet screen for sizing, 95 tons/hr of crushed coal at 3/8 inch	1	Horizontal vibrating screen, 4 feet wide x 16 feet long, low-noise suspension, standard positioning of water sprays, stainless steel deck for screening at 3/8 inch, carbon steel body; 10 hp
4. Sieve bends for partial dewatering and screening of 66 tons/hr of 28 mesh x 0 coal from 508 tons/hr of 3/8 inch x 0 coal	6	Reversible sieve bend, 7 feet wide, with deck of 1/8 inch Bixby-Zimmer Iso-Rod spaced for 1.2 mm opening, including feed box distributor, carbon steel body; 0 hp
5. Fines screens for finish screening of 66 tons/hr of 28 mesh x 0 coal from 508 tons/hr of 3/8 inch x 0 coal	6	Horizontal vibrating screen, 8 feet wide x 16 feet long, deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for sizing at 28 mesh, low-noise suspension, standard positioning of water sprays, carbon steel body; 20 hp

Area 3--Coarse Coal Cleaning

Item	No.	Description
1. Dense medium vessels for processing 298 tons/hr of 2 inch x 3/8 inch coal, using magnetite medium at nominal specific gravity of 1.55 for production of 253 tons/hr of float	2	Trough-type vessel, 7 feet wide, with single chain-and-flight conveyor for float and sink removals at opposite ends of vessel, float and sink inclines constructed from steel wedge wire for drainage of medium from float and sink products to bath, controlled level of bath, controlled distribution of medium recirculated to bath, carbon steel frame and tank, high carbon steel wear bars on conveyor; 20 hp
2. Rinse screens for 253 tons/hr of clean coal (float) at 2 inch x 3/8 inch from dense medium vessel	2	Horizontal vibrating screen, 6 feet wide x 16 feet long, low-noise suspension, standard positioning of water sprays, carbon steel frame, deck of 1/8 inch Bixby-Zimmer Iso-Rod spaced for 1 mm opening; 15 hp

(continued)

TABLE A-2 (continued)

Item	No.	Description
3. Rinse screens for 45 tons/hr of refuse (sink) from dense medium vessel	1	Horizontal vibrating screen, 4 feet wide x 16 feet long, low-noise suspension, standard positioning of water sprays, carbon steel frame, deck of 1/8 inch Bixby-Zimmer Iso-Rod spaced for 1 mm opening; 10 hp
4. Centrifuge for dewatering 253 tons/hr of 2 inch x 3/8 inch clean coal from rinse screens	2	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone-shaped basket of stainless steel screen; individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping; carbon steel body; 60 hp total

Area 4--Intermediate Coal Cleaning

Item	No.	Description
1. Dense medium cyclone feed sump for makeup of coal slurry comprising 442 tons/hr coal at 3/8 inch x 28 mesh and 2,290 tons/hr magnetite medium; nominal specific gravity of magnetite medium 1.55	2	Cylindrical tank, 14 feet diameter x 2 feet high, with 60 degree cone bottom and closed top, 7,000 gallons, ground-level installation, carbon steel
2. Pumps for feeding coal slurry to dense medium cyclones	2 + 1 spare	Centrifugal pump, 3,630 gpm, 70 feet total head; 200 hp
3. Dense medium cyclones for separation of 3/8 inch x 28 mesh coal at specific gravity 1.55	6	Dense medium cyclone, 24 inch diameter with tangential entry of feed and exit of clean coal tops, cone angle about 20 degrees, hard nickel or similarly abrasion-resistant iron

(continued)

TABLE A-2 (continued)

Item	No.	Description
4. Sieve bends for partial drainage of medium from 370 tons/hr of clean coal tops from dense medium cyclones	6	Reversible sieve bend, 7 feet wide, with deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 3/4 mm opening, including feed box distributor; 0 hp
5. Drain and rinse screens for 370 tons/hr clean coal tops at 3/8 inch x 28 mesh	6	Horizontal vibrating screen, 8 feet wide x 16 feet long, standard positioning of water sprays in rinse section, 2-compartment pan for separate collections of medium and rinse wate- low-noise suspension, deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 1/2 mm opening, carbon steel frame; 20 hp
6. Centrifuges for dewatering 370 tons/hr of 3/8 inch x 28 mesh clean coal from drain and rinse screens	3	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone-shaped basket of stainless steel screen; individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body; 85 hp total
7. Sieve bends for partial drainage of medium from 72 tons/hr of 3/8 inch x 28 mesh refuse from dense medium cyclones	2	Reversible sieve bend, 4 feet wide, with deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 3/4 mm opening, including feed box distributor; 0 hp
8. Drain and rinse screens for 72 tons/hr of 3/8 inch x 28 mesh refuse	2	Horizontal vibrating screen, 5 feet wide x 16 feet long, standard positioning of water sprays in rinse section, 2-compartment pan for separate collections of medium and rinse water, low-noise suspension, deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 1/2 mm opening, carbon steel frame; 12 hp

(continued)

TABLE A-2 (continued)

Item	No.	Description
9. Centrifuge for dewatering 72 tons/hr of 3/8 inch x 28 mesh refuse from drain and rinse screens	1	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone-shaped basket of stainless steel screen, individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body; 60 hp total
10. Dense medium recovery system for dilute medium from rinse screens in coarse and intermediate cleaning areas	4	Double-drum magnetite recovery unit with permanent magnets in drums, 30 inch diameter x 10 feet long drum, 2 drums in series/unit; complete with dilute medium sump, magnetite scraper, etc., installed at elevation above dense medium separators; carbon steel 10 hp/unit

Area 5--Fine Coal Cleaning

Item	No.	Description
1. Froth flotation feed sump for makeup of coal slurry at 10% solids using 66 tons/hr of 28 mesh x 0 coal	1	Cylindrical tank, 12-1/2 feet diameter x 2 feet high with 60 degree cone bottom and closed top, 5,500 gallons, ground-level installation, carbon steel
2. Pump for feeding coal slurry to froth flotation cells	1 + 1 spare	Centrifugal pump, 2,700 gpm, 60 feet total head; 75 hp
3. Froth flotation cells for treatment of 66 tons/hr of 28 mesh x 0 coal	1	Bank of 4 froth flotation cells with 300 ft^3/cell; provisions for agitation, aeration, and skimming of froth from cell; each bank arranged with 1 feed box and 1 tailings box; provisions for reagent storage and reagent feeding; carbon steel; 130 hp/bank

(continued)

TABLE A-2 (continued)

Item	No.	Description
4. Disk filter for filtration of 56 tons/hr clean coal from froth flotation	1	Continuous rotary vacuum disk filter, 12 feet, 6 inch diameter x 11 disk, 55 stainless steel wire cloth; complete with vacuum pumps and receiver, moisture trap, filtrate pump, and blower; 580 hp
5. Thickener receiving 2,360 gpm of refuse slurry (tailings) from froth flotation and filtrate from refuse filter	1	Single compartment bridge-supported thickener with 80 feet diameter reinforced-concrete tank; system includes drive unit and lifting device, rake mechanism, feed well, overflow arrangement, underflow arrangement, and instrumentation; rotation drive 5 hp, lifting drive 1 hp
6. Disk filter for filtration of 11 tons/hr refuse (underflow) from thickener	1	Continuous rotary vacuum disk filter, 12 feet, 6 inch diameter x 6 disk , stainless steel wire cloth; complete with vacuum pump and receiver, moisture trap, filtrate pump, and blower; 200 hp
7. Pump for returning 2,280 gpm of clarified water	2 + 1 spare	Centrifugal pump, 1,140 gpm, 150 feet total head; 75 hp

Area 6--Refuse Disposal

Item	No.	Description
1. Collecting conveyor for 128 tons/hr of 2 inch x 0 refuse	1	Horizontal and inclined belt conveyor, 400 feet long with 24-inch-wide belt, carbon steel; 15 hp
2. Refuse bin for truck loading	1	Storage bin, 16 feet wide x 26 feet long x 18 feet high on vertical sides, 13-feet-deep pyramidal bottom with fast opening slides for truck loading; 3.5 hp

(continued)

TABLE A-2 (continued)

Item	No.	Description
3. Trucks for transporting 128 tons/hr of 2 inch x 0 refuse 1 mile from coal cleaning plant to refuse disposal site	2	Off-highway diesel-electric dump truck, 100 ton payload, 100 $yard^3$ capacity, dump body for 2 inch x 0 moist, sluggish, abrasive refuse
4. Refuse disposal site for 30-year operation	1	"Dry" storage site with 26,000 acre-feet capacity for layered refuse and earth
5. Bulldozer for spreading refuse and earth in layers at disposal site	1	Diesel bulldozer; 100 hp

Area 7--Clean Coal Storage

Item	No.	Description
1. Collecting conveyor for 679 tons/hr of 2 inch x 0 cleaned coal	1	Horizontal conveyor, 300 feet long with 36-inch-wide belt, carbon steel; 20 hp
2. Transfer conveyors	2	Inclined conveyor, 200 feet long with 36-inch-wide belt, with belt scale, carbon steel; 50 hp
3. Stacking conveyors for distributing coal along the tops of 2 parallel and adjacent wedge-shaped open piles, each of 150,000 tons	2	Elevated horizontal conveyor, 1,000 feet long with 1 traveling tripper, 36-inch-wide belt, carbon steel; 40 hp
4. Hoppers under stockpile for reclaiming cleaned coal from stockpiles	20	Reclaiming hopper with 16 feet x 16 feet top opening, 4-feet-deep pyramid, and 26 inch x 26 inch bottom opening, carbon steel
5. Pan feeders for withdrawing 1,350 tons/hr, 2 inch x 0 cleaned coal from reclaiming hoppers	20	Vibrating pan feeder with 30 inch wide x 48 inch long pan, carbon steel; 1.5 hp vibrator

(continued)

TABLE A-2 (continued)

Item	No.	Description
6. Collecting conveyors for 1,350 tons/hr cleaned coal from pan feeders	2	Horizontal conveyor 1,000 feet long with 36-inch-wide belt, carbon steel; 50 hp
7. Tunnels for collecting conveyors	2	Steel-reinforced concrete tunnel 8 feet wide x 6 feet deep x 1,000 feet long
8. Tunnel sump pump	2 + 1 spare	Centrifugal pump, 60 gpm, 30 feet head, carbon steel; 1 hp
9. Transfer conveyor	1	Horizontal conveyor, 320 feet long with 36-inch-wide belt, carbon steel; 15 hp
10. Tunnel for transfer conveyor	1	Steel-reinforced concrete tunnel 8 feet wide x 6 feet deep x 320 feet long
11. Tunnel sump pump	1 + 1 spare	Centrifugal pump, 60 gpm, 30 feet head, carbon steel; 1 hp
12. Automatic sampling of coal from cleaning plant to stockpile	1	Automatic sampler of plate or similar type conforming with ASTM sampling requirements, primary sampling from 339 tons/hr 2 inch x 0 coal from each of 2 transfer conveyors, combination of primary samples to a single sample of cleaning plant product
13. Bulldozer for servicing clean coal stockpile	1	Diesel bulldozer; 100 hp

TABLE A-3. PCC II PROCESS

(CLEANING AT INTERMEDIATE AND FINE SIZES)

MATERIAL BALANCE - (5% S COAL)

	Stream No.	1	2	3	4	5	6	7
	Description	Raw coal to sizing (3 in. x 0)	Coal to crusher (3 in. x 3/4 in.)	Coal from raw coal screen (3/4 in. x 0)	Coal to fines screens (3/4 in. x 0)	Oversize from fines screens (3/4 in. x 28 m)	Undersize from fines screen (28 m x 0)	Feed to low-gravity cyclones (3/4 in. x 28 m)
1	Total stream, tons/hr	858.2	229.0	760.7	1,016.6	746.0	478.7	2,970.9[a]
2								
3	Stream components, tons/hr							
4	Coal, bone-dry	803.4	207.8	595.6	803.4	647.9	155.5	647.9
5	Water, total	54.8	21.2	165.1	213.2	98.1	323.2	2,323.0
6								
7								
8	Gal/min				3,203.1			12,000.7
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
32								
33	Ash, tons/hr	134.2	34.7	99.5	134.2	108.2	26.0	108.2
34	Pyritic S, tons/hr	26.9	7.0	19.9	26.9	21.7	5.2	21.7
35	Total S, tons/hr	40.2	10.4	29.8	40.2	32.4	7.8	32.4
36								
37	Btu/lb, bone-dry	12,000	12,000	12,000	12,000	12,000	12,000	12,000
38								
39								
40								

(continued)

TABLE A-3 (continued)

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a. Excluding 1,057.5 tons/hr of magnetite.

(continued)

TABLE A-3 (continued)

	8	9	10	11
	Clean coal from low-gravity cyclone centrifuge (3/4 in. x 28 m)	Feed to high-gravity cyclones (3/4 in. x 28 m)	Middling from high-gravity cyclone centrifuge (3/4 in. x 28 m)	Refuse from high-gravity cyclone centrifuge (3/4 in. x 28 m)
1	341.6	1,310.0[b]	249.2	112.3
2				
3				
4	314.8	333.1	229.7	103.4
5	26.8	976.9	19.5	8.9
6				
7				
8		5,467.5		
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33	20.6	87.6	30.9	56.7
34	4.1	17.6	6.2	11.4
35	9.3	23.1	10.0	13.1
36				
37	13,500	10,700	12,500	
38				
39				
40				

b. Excluding 1,726.0 tons/hr of magnetite.

(continued)

TABLE A-3 (continued)

	12	13	14	15
	Feed to froth flotation (28 m x 0)	Middling from flotation filter (28 m x 0)	Refuse to flotation thickener (28 m x 0)	Refuse from flotation filter (28 m x 0)
1	1,611.0	180.0	1,371.6	34.8
2				
3				
4	155.5	130.3	25.2	25.2
5	1,455.5	49.7	1,346.4	9.6
6				
7				
8	6,276.9		5,459.3	
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33	26.0	10.9	15.1	15.1
34	5.2	2.2	3.0	3.0
35	7.8	4.4	3.4	3.4
36				
37	12,000	13,200		
38				
39				
40				

(continued)

TABLE A-3 (continued)

	16 Clarified water	17 Makeup water	18 Refuse to disposal pond	19 Middling to stockpile
1	1,336.8	59.7	147.1	429.2
2				
3				
4			128.6	360.0
5	1,336.8	59.7	18.5	69.2
6				
7				
8	5,347.2	238.8		
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33			71.8	41.8
34			14.4	8.4
35			16.5	14.4
36				
37				12,700
38				
39				
40				

TABLE A-4. PCC II PROCESS

(CLEANING AT INTERMEDIATE AND FINE SIZES)

EQUIPMENT LIST - BASE CASE (5% S COAL)

NOTE: Coal tonnages are listed as bone-dry coal excluding the internal moisture of 3.5% in the base case coal. However, equipment sizes include the handling of internal and of surface moisture.

Area 1--Coal Receiving and Storage

Item	No.	Description
1. Unloading conveyors for conveying 1,600 tons/hr, 3 inch x 0 raw coal from unloading station to stockpiles	2	Inclined conveyor, 500 feet long, with 1 fixed tripper, 48-inch-wide belt, carbon steel, with tramp-iron magnet; 125 hp
2. Stacking conveyors for distributing coal along the tops of 2 parallel and adjacent wedge-shaped open piles, each of 175,000 tons	2	Elevated horizontal conveyor, 1,000 feet long with 1 traveling tripper, 48-inch-wide belt, telescoping chute, carbon steel; 40 hp
3. Hoppers for reclaiming 803 tons/hr of 3 inch x 0 raw coal from stockpiles	20	Reclaiming hopper with 14 feet x 14 feet top opening, 3-1/2 feet deep pyramid, and 24 inch x 24 inch bottom opening, carbon steel
4. Pan feeders for withdrawing 803 tons/hr of 3 inch x 0 raw coal from reclaiming hoppers	20	Vibratory pan feeder with 26 inch wide x 48 inch long pan, carbon steel; 1.5 hp vibrator
5. Collecting conveyors for 803 tons/hr of 3 inch x 0 raw coal from pan feeders	2	Horizontal conveyor, 1,000 feet long with 36-inch-wide belt, carbon steel; 35 hp
6. Tunnels for collecting conveyors	2	Steel-reinforced concrete tunnel 8 feet wide x 6 feet deep x 1,000 feet long
7. Tunnel sump pump	2 + 1 spare	Centrifugal pump, 60 gpm, 30 feet head, carbon steel; 1 hp

(continued)

TABLE A-4 (continued)

Item	No.	Description
8. Transfer conveyor	1	Horizontal conveyor, 320 feet long with 36-inch-wide belt, carbon steel; 10 hp
9. Tunnel for transfer conveyor	1	Steel-reinforced concrete tunnel, 7 feet wide x 6 feet deep x 320 feet long
10. Tunnel sump pump	1 + 1 spare	Centrifugal pump, 60 gpm, 30 feet head, carbon steel; 1 hp
11. Delivery conveyor for 803 tons/hr of 3 inch x 0 raw coal to raw coal sizing area	2	Inclined conveyor, enclosed, 600 feet long, 36-inch-wide belt, with belt scale, carbon steel: 75 hp
12. Automatic sampling of coal from stockpile to raw coal sizing area	1	Automatic sampler of plate or similar type conforming with ASTM sampling requirements, primary sampling from 402 tons/hr of 3 inch x 0 coal from each of 2 delivery conveyors, combination of primary samples to a single head sample
13. Bulldozer for servicing raw coal storage piles	1	Diesel bulldozer; 100 hp

Area 2--Raw Coal Sizing

Item	No.	Description
1. Raw coal screens for sizing 803 tons/hr of 3 inch x 0 coal to 208 tons/hr, 3 inch x 3/4 inch, and 595 tons/hr, 3/4 inch x 0	4	Horizontal vibrating screen, 6 feet wide x 16 feet long, low-noise suspension, standard positioning of water sprays, stainless steel flanged screen plate for sizing at 3/4 inch, carbon steel body; 15 hp

(continued)

TABLE A-4 (continued)

Item	No.	Description
2. Crusher for reducing 208 tons/hr of 3 inch x 3/4 inch coal to 3/4 inch x 0	1	Single roll crusher with 24 inch x 48 inch roll and stationary breaker plate, materials of construction suited to secondary crushing of medium-hard bituminous coal; 60 hp
3. Crusher screen for sizing, 208 tons/hr of crushed coal at 3/4 inch	1	Horizontal vibrating screen, 8 feet wide x 16 feet long, low-noise suspension, standard positioning of water sprays, stainless steel screen plate for sizing at 3/4 inch, carbon steel body; 20 hp
4. Sieve bends for partial dewatering and screening of 155 tons/hr of 28 mesh x 0 coal from 803 tons/hr of 3/4 inch x 0 coal	8	Reversible sieve bend, 7 feet wide, with deck of 1/8 inch Bixby-Zimmer Iso-Rod spaced for 1.2 mm opening, including feed box distributor, carbon steel body; 0 hp
5. Fines screens for finish screening of 155 tons/hr of 28 mesh x 0 coal from 803 tons/hr of 3/4 inch x 0 coal	8	Horizontal vibrating screen, 8 feet wide x 16 feet long, deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for sizing at 28 mesh, low-noise suspension, standard positioning of water sprays, carbon steel body; 20 hp

Area 3--Low Gravity Cleaning

Item	No.	Description
1. Dense medium cyclone feed sump for makeup of coal slurry comprising 648 tons/hr coal at 3/4 inch x 28 mesh and 3,360 tons/hr magnetite medium; nominal specific gravity of magnetite medium 1.34	3	Cylindrical tank, 14 feet diameter x 2 feet high, with 60 degree cone bottom and closed top, 7,000 gallon ground-level installation, carbon steel

(continued)

TABLE A-4 (continued)

Item	No.	Description
2. Pumps for feeding coal slurry to dense medium cyclones	3 + 2 spare	Centrifugal pump, 4,000 gpm, 70 feet total head; 200 hp
3. Dense medium cyclones for separation of 3/4 inch x 28 mesh coal at specific gravity 1.34	12	Dense medium cyclone, 20 inch diameter with tangential entry of feed and exit of clean coal tops, cone angle about 20 degrees, hard nickel or similarly abrasion-resistant iron
4. Sieve bends for partial drainage of medium from 315 tons/hr clean coal tops (3/4 inch x 28 mesh) from dense medium cyclones	6	Reversible sieve bend, 6 feet wide, with deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 3/4 mm opening, including feed box distributor; 0 hp
5. Drain and rinse screens for 315 tons/hr clean coal tops at 3/4 inch x 28 mesh	6	Horizontal vibrating screen, 7 feet wide x 16 feet long, standard positioning of water sprays in rinse section, 2-compartment pan for separate collections of medium and rinse water, low-noise suspension, deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 1/2 mm opening, carbon steel frame; 18 hp
6. Centrifuges for dewatering 315 tons/hr of 3/4 inch x 28 mesh clean coal from drain and rinse screens	3	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone-shaped basket of stainless steel screen; individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body; 60 hp total
7. Sieve bends for partial drainage of medium from 333 tons/hr of 3/4 inch x 28 mesh bottoms from low-gravity cyclone	6	Reversible sieve bend, 6 feet wide, with deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 3/4 mm opening, including feed box distributor; 0 hp
8. Drain screens for 333 tons/hr of 3/4 inch x 28 mesh coal	6	Horizontal vibrating screen, 7 feet wide x 16 feet long, low-noise suspension, deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 1/2 mm opening, carbon steel frame; 18 hp

(continued)

TABLE A-4 (continued)

Area 4--High-Gravity Cleaning

Item	No.	Description
1. Dense medium cyclone feed sump for makeup of coal slurry comprising 331 tons/hr coal at 3/4 inch x 28 mesh and 1,726 tons/hr magnetite medium; nominal specific gravity of magnetite medium 1.55	2	Cylindrical tank, 12-1/2 feet diameter x 2 feet high, with 60 degree cone bottom and closed top, 5,150 gallon, ground-level installation, carbon steel
2. Pumps for feeding coal slurry to dense medium cyclones	2 + 1 spare	Centrifugal pump, 2,740 gpm, 70 feet total head; 120 hp
3. Dense medium cyclones for separation of 3/4 inch x 28 mesh coal at specific gravity 1.55	8	Dense medium cyclone, 20 inch diameter with tangential entry of feed and exit of clean coal tops, cone angle about 20 degrees, hard nickel or similarly abrasion-resistant iron
4. Sieve bends for partial drainage of medium from 230 tons/hr middling coal tops (3/4 inch x 28 mesh) from dense medium cyclones	4	Reversible sieve bend, 5 feet wide, with deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 3/4 mm opening, including feed box distributor; 0 hp
5. Drain and rinse screens for 230 tons/hr middling coal tops at 3/4 inch x 28 mesh	4	Horizontal vibrating screen, 6 feet wide x 16 feet long, standard positioning of water sprays in rinse section, 2-compartment pan for separate collections of medium and rinse water, low-noise suspension, deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 1/2 mm opening, carbon steel frame; 15 hp
6. Centrifuges for dewatering 230 tons/hr of 3/4 inch x 28 mesh coal from drain and rinse screens	2	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone-shaped basket of stainless steel screen; individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body; 60 hp total

(continued)

TABLE A-4 (continued)

Item	No.	Description
7. Sieve bends for partial drainage of medium from 103 tons/hr of refuse bottoms (3/4 inch x 28 mesh) from dense medium cyclones	2	Reversible sieve bend, 5 feet wide, with deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 3/4 mm opening, including feed box distributor; 0 hp
8. Drain and rinse screens for 103 tons/hr of 3/4 inch x 28 mesh refuse	2	Horizontal vibrating screen, 7 feet wide x 16 feet long, standard positioning of water sprays in rinse section, 2-compartment pan for separate collections of medium and rinse water, low-noise suspension, deck of 3/32 inch Bixby-Zimmer Iso-Rod spaced for 1/2 mm opening, carbon steel frame; 18 hp
9. Centrifuge for dewatering 103 tons/hr of 3/4 inch x 28 mesh refuse from drain and rinse screens	1	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone-shaped basket of stainless steel screen, individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body; 60 hp total
10. Dense medium recovery system for dilute medium from rinse screens in clean coal and middling coal cleaning sections	4	Double-drum magnetite recovery unit with permanent magnets in drums, 30 inch diameter x 10 feet long drum, 2 drums in series/unit; complete with dilute medium sump, magnetite scraper, etc., installed at elevation above dense medium separators; carbon steel; 5 hp

Area 5--Fine Coal Cleaning

Item	No.	Description
1. Froth flotation feed sump for makeup of coal slurry at 10% solids using 155 tons/hr of 28 mesh x 0 coal	2	Cylindrical tank, 13-1/2 feet diameter x 2 feet high with 60 degree cone bottom and closed top, 6,300 gallon, ground-level installation, carbon steel

(continued)

TABLE A-4 (continued)

Item	No.	Description
2. Pump for feeding coal slurry to froth flotation cells	2 + 1 spare	Centrifugal pump, 3,140 gpm, 60 feet total head; 75 hp
3. Froth flotation cells for treatment of 155 tons/hr of 28 mesh x 0 coal	2	Bank of 5 froth flotation cells with 300 ft^3/cell; provisions for agitation, aeration, and skimming of froth from cell; each bank arranged with feed box and tailings box; provisions for reagent storage and reagent feeding; carbon steel; 75 hp
4. Disk filter for filtration of 130 tons/hr middling coal from froth flotation	3	Continuous rotary vacuum disk filter, 12 feet, 6 inch diameter x 10 disk, stainless steel wire cloth; complete with vacuum pumps and receiver, moisture trap, filtrate pump, and blower; 525 hp
5. Thickener receiving 5,800 gpm refuse slurry (tailings) from froth flotation and filtrate from refuse filter	1	Single compartment bridge-supported thickener with 120 feet diameter reinforced concrete tank; system includes drive unit and lifting device, rake mechanism, feed well, overflow arrangement, underflow arrangement, and instrumentation; rotation drive 5 hp, lifting drive 1 hp
6. Disk filter for filtration of 25 tons/hr refuse (underflow) from thickener	1	Continuous rotary vacuum disk filter, 12 feet, 6 inch diameter x 11 disk, stainless steel wire cloth; complete with vacuum pump and receiver, moisture trap, filtrate pump, and blower, 580 hp
7. Pump for returning 5,350 gpm of clarified water	2 + 1 spare	Centrifugal pump, 2,670 gpm, 150 feet total head; 175 hp

Area 6--Refuse Disposal

Item	No.	Description
1. Collecting conveyor for 129 tons/hr of 3/4 inch x 0 refuse	1	Horizontal and inclined belt conveyor, 400 feet long with 24-inch-wide belt, carbon steel, 15 hp

(continued)

TABLE A-4 (continued)

Item	No.	Description
2. Refuse bin for truck loading	1	Storage bin, 16 feet wide x 26 feet long x 18 feet high on vertical sides, 13 feet deep pyramidal bottom with fast opening slides for truck loading
3. Trucks for transporting 129 tons/hr of 3/4 inch x 0 refuse 1 mile from coal cleaning plant to refuse disposal site	2	Off-highway diesel-electric dump truck, 100 ton payload, 100 yd^3 capacity, dump body for 3/4 inch x 0 moist, sluggish abrasive refuse
4. Refuse disposal site for 30-year operation	1	"Dry" storage site with 26,000 acre-feet capacity for layered refuse and earth
5. Bulldozer for spreading refuse and earth in layers at disposal site	1	Diesel bulldozer; 100 hp

Area 7-- Clean Coal Storage

Item	No.	Description
1. Collecting conveyor for 315 tons/hr of 3/4 inch x 28 mesh cleaned coal	1	Horizontal conveyor, 300 feet long with 36-inch-wide belt, carbon steel; 10 hp
2. Transfer conveyors	1	Inclined conveyor, 250 feet long with 36-inch-wide belt, with belt scale, carbon steel; 60 hp
3. Stacking conveyors for distributing coal along the tops of 2 parallel and adjacent wedge-shaped open piles, each of 75,000 tons	2	Elevated horizontal conveyor, 500 feet long with 1 traveling tripper, 36-inch-wide belt, carbon steel; 25 hp
4. Hoppers under stockpile for reclaiming cleaned coal from stockpiles	20	Reclaiming hopper with 14 feet x 14 feet top opening, 3-1/2 feet deep pyramid, and 24 inch x 24 inch bottom opening, carbon steel

(continued)

TABLE A-4 (continued)

Item	No.	Description
5. Pan feeders for withdrawing 700 tons/hr, 3/4 inch x 28 mesh cleaned coal from reclaiming hoppers	20	Vibrating pan feeder with 26 inch wide x 48 inch long pan, carbon steel; 1.5 hp vibrator
6. Collecting conveyors for 700 tons/hr cleaned coal from pan feeders	2	Horizontal conveyor 500 feet long with 36-inch-wide belt, carbon steel, 20 hp
7. Tunnels for collecting conveyors	2	Steel-reinforced concrete tunnel 8 feet wide x 6 feet deep x 500 feet long
8. Tunnel sump pump	2 + 1 spare	Centrifugal pump, 60 gpm, 30 feet head, carbon steel; 1 hp
9. Transfer conveyor	1	Horizontal conveyor, 250 feet long with 36-inch-wide belt, carbon steel; 10 hp
10. Tunnel for transfer conveyor	1	Steel-reinforced concrete tunnel 8 feet wide x 6 feet deep x 250 feet long
11. Tunnel sump pump	1 + 1 spare	Centrifugal pump, 60 gpm, 30 feet head, carbon steel; 1 hp
12. Automatic sampling of coal from cleaning plant to stockpile	1	Automatic sampler of plate or similar type conforming with ASTM sampling requirements, primary sampling from 315 tons/hr 3/4 inch x 28 mesh coal from transfer conveyor

Area 8--Middling Coal Storage

Item	No.	Description
1. Collecting conveyor for 360 tons/hr of 3/4 inch x 0 cleaned coal	1	Horizontal conveyor, 300 feet long with 36-inch-wide belt, carbon steel; 10 hp
2. Transfer conveyors	1	Inclined conveyor, 250 feet long with 36-inch-wide belt, with belt scale, carbon steel; 60 hp

(continued)

TABLE A-4 (continued)

	Item	No.	Description
3.	Stacking conveyors for distributing coal along the tops of 2 parallel and adjacent wedge-shaped open piles, each of 75,000 tons	2	Elevated horizontal conveyor, 500 feet long with 1 traveling tripper, 36-inch-wide belt, carbon steel; 25 hp
4.	Hoppers under stockpile for reclaiming middling coal from stockpiles	20	Reclaiming hopper with 14 feet x 14 feet top opening, 3-1/2 feet deep pyramid, and 24 inch x 24 inch bottom opening, carbon steel
5.	Pan feeders for withdrawing 700 tons/hr, 3/4 inch x 0 middling coal from reclaiming hoppers	20	Vibrating pan feeder with 26 inch wide x 48 inch long pan, carbon steel; 1.5 hp vibrator
6.	Collecting conveyors for 700 tons/hr cleaned coal from pan feeders	2	Horizontal conveyor 500 feet long with 36-inch-wide belt, carbon steel, 20 hp
7.	Tunnels for collecting conveyors	2	Steel-reinforced concrete tunnel 8 feet wide x 6 feet deep x 500 feet long
8.	Tunnel sump pump	2 + 1 spare	Centrifugal pump, 60 gpm, 30 feet head, carbon steel; 1 hp
9.	Transfer conveyor	1	Horizontal conveyor, 250 feet long with 36-inch-wide belt, carbon steel; 10 hp
10.	Tunnel for transfer conveyor	1	Steel-reinforced concrete tunnel 8 feet wide x 6 feet deep x 250 feet long
11.	Tunnel sump pump	1 + 1 spare	Centrifugal pump, 60 gpm, 30 feet head, carbon steel; 1 hp
12.	Automatic sampling of coal from cleaning plant to stockpile	1	Automatic sampler of plate or similar type conforming with ASTM sampling requirements, primary sampling from 360 tons/hr 3/4 inch x 0 middling coal from transfer conveyor
13.	Bulldozer for servicing stockpile	1	Diesel bulldozer; 100 hp

TABLE A-5. PCC III PROCESS

(CLEANING AT COARSE AND FINE SIZES)

MATERIAL BALANCE - BASE CASE (5% S COAL)

	Stream No.	1	2	3	4	5	6	7
	Description	Raw coal to sizing (3 in. x 0)	Coal to crusher (3 in.x 3/4 in.)	Coal from raw coal screen (3/4 in. x 0)	Coal to fines screens (1-1/2 in. x 0)	Oversize from fines screens (1-1/2 in.x 8 m)	Oversize from classifying sieve bend (8 m x 200 m)	Undersize from classifying sieve bend (200 m x 0)
1	Total stream, tons/hr	864.5	230.7	789.2	1,046.9	618.8	432.3	205.4
2								
3	Stream components, tons/hr							
4	Coal, bone-dry	809.2	209.3	599.9	809.2	544.0	250.3	14.9
5	Water, total	55.2	21.4	189.3	237.7	74.8	182.0	190.5
6								
7								
8	Gal/min				3,318.0			
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
32								
33	Ash, tons/hr	135.1	34.9	100.2	135.1	90.8	41.8	2.5
34	Pyritic S, tons/hr	27.1	7.0	20.1	27.1	18.2	8.4	0.5
35	Total S, tons/hr	40.5	10.5	30.0	40.5	27.2	12.5	0.8
36								
37	Btu/lb, bone-dry	12,000	12,000	12,000	12,000	12,000	12,000	12,000
38								
39								
40								

(continued)

TABLE A-5 (continued)

(continued)

TABLE A-5 (continued)

	8	9	10	11
	Feed to DM cyclones (1-1/2 in. x 8 m)	Clean coal from DM cyclone centrifuge (1-1/2 in.x 8 m)	Refuse from DM cyclone centrifuge (1-1/2 in.x 8 m)	Feed to concentrating table (8 m x 200 m)
1	2,139.3[a]	492.1	92.0	648.5
2				
3				
4	544.0	458.3	85.7	250.3
5	1,595.3	33.8	6.3	398.2
6				
7				
8	8,929.0			2,325.0
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33	90.8	47.1	43.7	41.8
34	18.2	9.5	8.7	8.4
35	27.2	17.0	10.2	12.5
36				
37	12,000	12,900		12,000
38				
39				
40				

a. Excluding 1,243.0 tons/hr of magnetite.

(continued)

TABLE A-5 (continued)

	12	13	14	15
	Dressing water to concentrating table	Coal concentrate from table (8 m x 200 m)	Clean coal from table centrifuge (8 m x 200 m)	Clean coal from table filter (200 m x 0)
1	129.7	686.6	235.0	20.5
2				
3				
4		212.0	212.0	14.9
5	129.7	474.6	23.0	5.6
6				
7				
8	518.8	2,518.6		
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33		23.0	23.0	2.5
34		4.6	4.6	0.5
35		8.1	8.1	0.8
36				
37		12,800	12,800	12,000
38				
39				
40				

(continued)

TABLE A-5 (continued)

	16	17	18	19
	Total fine clean coal (8 m x 0)	Refuse from table centrifuge (8 m x 200 m)	Clarified water	Makeup water
1	255.5	42.6	555.8	17.8
2				
3				
4	226.9	38.3		
5	28.6	4.3	555.8	17.8
6				
7				
8			2,223.2	71.2
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33	25.5	18.8		
34	5.1	3.8		
35	8.9	4.4		
36				
37	12,800			
38				
39				
40				

(continued)

TABLE A-5 (continued)

	20	21		
	Refuse to disposal pond (8 m x 200 m)	Clean coal to stockpile (1-1/2 in.x 0)		
1	134.6	747.6		
2				
3				
4	124.0	685.2		
5	10.6	62.4		
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33	62.5	72.6		
34	12.5	14.6		
35	14.6	25.9		
36				
37		12,900		
38				
39				
40				

TABLE A-6. PCC III PROCESS

(CLEANING AT COARSE AND FINE SIZES)

EQUIPMENT LIST - BASE CASE (5% S COAL)

NOTE: Coal tonnages are listed as bone-dry coal excluding the internal moisture of 3.5% in the base case coal. However, equipment sizes include the handling of internal and of surface moisture.

Area 1--Coal Receiving and Storage

Item	No.	Description
1. Unloading conveyors for conveying 1,600 tons/hr, 3 in. x 0 raw coal from unloading station to stockpiles	2	Inclined conveyor, 500 ft long, with 1 fixed tripper, 48 in. wide belt, carbon steel, with tramp iron magnet, 125 hp
2. Stacking conveyors for distributing coal along the tops of 2 parallel and adjacent wedge-shaped open piles, each of 175,000 tons	2	Elevated horizontal conveyor, 1,000 ft long with 1 traveling tripper, 48 in. wide belt, telescoping chute, carbon steel, 40 hp
3. Hoppers for reclaiming 809 tons/hr of 3 in. x 0 raw coal from stockpiles	20	Reclaiming hopper with 14 ft x 14 ft top opening, 3-1/2 ft deep pyramid, and 24 in. x 24 in. bottom opening, carbon steel
4. Pan feeders for withdrawing 809 tons/hr of 3 in. x 0 raw coal from reclaiming hoppers	20	Vibratory pan feeder with 26 in. wide x 48 in. long pan, carbon steel, 1.5 hp vibrator
5. Collecting conveyors for 809 tons/hr of 3 in. x 0 raw coal from pan feeders	2	Horizontal conveyor, 1,000 ft long with 36 in. wide belt, carbon steel, 35 hp
6. Tunnels for collecting conveyors	2	Steel reinforced concrete tunnel 8 ft wide x 6 ft deep x 1,000 ft long
7. Tunnel sump pump	2	Centrifugal pump, 60 gpm, 30 ft head, carbon steel, 1 hp (1 spare)

(continued)

TABLE A-6 (continued)

Item	No.	Description
8. Transfer conveyor	1	Horizontal conveyor, 320 ft long with 36 in. wide belt, carbon steel, 10 hp
9. Tunnel for transfer conveyor	1	Steel reinforced concrete tunnel, 7 ft wide x 6 ft deep x 320 ft long
10. Tunnel sump pump	1	Centrifugal pump, 60 gpm, 30 ft head, carbon steel, 1 hp (1 spare)
11. Delivery conveyor for 809 tons/hr 3 in. x 0 raw coal to raw coal sizing area	2	Inclined conveyor, enclosed, 600 ft long, 36 in. wide belt, with belt scale, carbon steel, 75 hp
12. Automatic sampling of coal from stockpile to raw coal sizing area	1	Automatic samples of plate or similar type conforming with ASTM sampling requirements, primary sampling from 405 tons/hr, 3 in. x 0 coal from each of 2 delivery conveyors, combination of primary samples to a single head sample.
13. Bulldozer for servicing raw coal storage piles	1	Diesel bulldozer, 100 hp

Area 2--Raw Coal Sizing

Item	No.	Description
1. Raw coal screens for sizing 809 tons/hr, 3 in. x 0 coal to 209 tons/hr, 3 in. x 3/4 in. and 600 tons/hr, 3/4 in. x 0	4	Horizontal vibrating screen, 6 ft wide x 16 ft long, low-noise suspension, standard positioning of water sprays, stainless steel flanged screen plate for sizing at 3/4 in., carbon steel body, 15 hp

(continued)

TABLE A-6 (continued)

Item	No.	Description
2. Crusher for reducing 209 tons/hr, 3 in. x 3/4 in. coal to 1-1/2 in. x 0	1	Single roll crusher with 24 in. x 36 in. roll and stationary breaker plate, materials of construction suited to secondary crushing of medium hard bituminous coal, 25 hp
3. Prewet screen for sizing, 209 tons/hr of crushed coal at 1-1/2 in.	1	Horizontal vibrating screen, 6 ft wide x 16 ft long, low-noise suspension, standard positioning of water sprays, stainless steel screen plate for sizing at 1-1/2 in., carbon steel body, 15 hp
4. Sieve bends for dewatering and screening, at 9 mesh, of 209 tons/hr of coal at 1-1/2 in. x 0 and 600 tons/hr of coal at 3/4 in. x 0	8	Reversible sieve bend, 7 ft wide, with deck of 1/8 in. Bixby-Zimmer Iso-Rod spaced for 2.0 mm opening, including feed box distributor, carbon steel body, 0 hp
5. Fines screens for finish screening, at 8 mesh, of oversize from sieve bends receiving 209 tons/hr coal at 1-1/2 in. x 0 and 600 tons/hr coal at 3/4 in. x 0	8	Horizontal vibrating screen, 8 ft wide x 16 ft long, low-noise suspension, standard positioning of water sprays, stainless steel deck for sizing, 1-1/2 in. x 0 and 3/4 in. x 0 coal at 8 mesh, carbon steel body, 20 hp
6. Sieve bends for screening of 15 tons/hr of 200 mesh x 0 coal from 265 tons/hr of 8 mesh x 0 coal	8	Reversible sieve bend, 5 ft wide, with deck of 3/32 in. Bixby-Zimmer Iso-Rod spaced for 0.21 mm opening, including feed box distributor, carbon steel body, 0 hp

Area 3--Coarse Coal Cleaning

Item	No.	Description
1. Dense medium cyclone feed sumps for makeup of coal slurry comprising 544 tons/hr coal at 1-1/2 in. x 8 mesh and 2,819 tons/hr magnetite medium, nominal specific gravity of magentite medium 1.55	3	Cylindrical tank, 13 ft dia x 2 ft high, with 60 degree cone bottom and closed top, 5,700 gal, ground-level installation, carbon steel

(continued)

TABLE A-6 (continued)

Item	No.	Description
2. Pumps for feeding coal slurry to dense medium cyclones	3	Centrifugal pump, 3,000 gpm, 70 ft total head, 150 hp
3. Dense medium cyclones for separation of 1-1/2 in. x 8 mesh coal at specific gravity 1.55	6	Dense medium cyclone, 28 in. dia, with tangential entry of feed and exit of clean coal tops, cone angle about 20 degrees, hard nickel or similarly abrasion-resistant iron
4. Sieve bends for partial drainage of medium from clean coal tops from dense medium cyclones	8	Reversible sieve bend, 7 ft wide, with deck of 3/32 in. Bixby-Zimmer Iso-Rod spaced for 3/4 mm opening, including feed box distributor, carbon steel body, 0 hp
5. Drain and rinse screens for 458 tons/hr clean coal tops at 1-1/2 in. x 8 mesh	8	Horizontal vibrating screen 8 ft wide x 16 ft long, standard positioning of water sprays in rinse section, 2-compartment pan for separate collections of medium and rinse water, low-noise suspension, deck of 3/32 in. Bixby-Zimmer Iso-Rod spaced for 1/2 mm opening, carbon steel frame, 20 hp
6. Centrifuges for dewatering 458 tons/hr of 1-1/2 in. x 8 mesh clean coal from drain and rinse screens	4	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone-shaped basket of stainless steel screen, individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body, 60 hp total
7. Sieve bends for partial drainage of medium from 86 tons/hr of 1-1/2 in. x 8 mesh refuse	2	Reversible sieve bend, 5 ft wide, with deck of 3/32 in. Bixby-Zimmer Iso-Rod spaced for 3/4 mm opening, including feed box distributor, carbon steel body, 0 hp

(continued)

TABLE A-6 (continued)

Item	No.	Description
8. Drain and rinse screens for 86 tons/hr of 1-1/2 in. x 8 mesh refuse	2	Horizontal vibrating screen, 6 ft wide x 16 ft long, standard positioning of water sprays in rinse section, 2-compartment pan for separate collections of medium and rinse water, low-noise suspension, deck of 3/32 in. Bixby-Zimmer Iso-Rod spaced for 1/2 mm opening, carbon steel frame, 15 hp
9. Centrifuge for dewatering 86 tons/hr of 1-1/2 in. x 8 mesh refuse	1	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone-shaped basket of stainless steel screen, individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body, 60 hp total
10. Dense medium recovery system for dilute medium from rinse screens in coarse and intermediate cleaning areas	4	Double-drum magnetite recovery unit with permanent magnets in drums, 30 in. dia x 8 ft long drum, 2 drums in series/unit, complete with dilute medium sump, magnetite scraper, etc., installed at elevation above dense medium separators, carbon steel, 10 hp/unit

Area 4--Fine Coal Cleaning

Item	No.	Description
1. Table feed sump for makeup of coal slurry at water to solids ratio of 1.5 using 250 tons/hr of 8 x 200 mesh coal	3	Cylindrical tank 8 ft dia x 2 ft high with 60 degree cone bottom and closed top, 1,620 gal, ground-level installation, carbon steel

(continued)

TABLE A-6 (continued)

Item	No.	Description
2. Pump for feeding coal slurry to concentrating tables	3	Centrifugal pump, 800 gpm, 20 ft total head, 15 hp (1 spare)
3. Concentrating tables receiving 250 tons/hr of 8 x 200 mesh feed	18	Double deck coal washing table (36 decks, total) mounted 4 decks high, 134 ft^2/deck, cable-suspended, including "head motion" oscillator for each double deck unit, revolving feed distributor servicing each 6 decks (6 distributors for total system), 3 hp/double deck table, 1 hp/distributor
4. Sieve bends for partial dewatering of 212 tons/hr of 8 x 200 mesh clean coal from tables	3	Reversible sieve bend, 7 ft wide, with deck of 1/16 in. Bixby-Zimmer Iso-Rod spaced for 0.15 mm opening, including feed box distributor, carbon steel body, 0 hp
5. Centrifuges for dewatering 212 tons/hr of 8 x 200 mesh clean coal from table sieve bend	2	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone-shaped basket of stainless steel screen for dewatering 8 x 200 mesh feed, individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body, 85 hp total
6. Thickener receiving about 1,800 gpm of slurry, comprising 200 mesh x 0 slurry from raw coal sizing section and underflow water from table concentrate sieve bend	1	Single compartment bridge supported thickener with 70 ft dia reinforced concrete tank, system includes drive unit and lifting device, rake mechanism, feed well, overflow arrangement, underflow arrangement, and instrumentation, rotation drive, 5 hp, lifting device, 1 hp

(continued)

TABLE A-6 (continued)

Item	No.	Description
7. Disk filter for filtration of thickener underflow containing 15 tons/hr coal at 200 mesh x 0	1	Continuous rotary vacuum disk filter, 12 ft, 6 in. dia x 6 ft disk stainless steel wire cloth, complete with vacuum pump and receiver, moisture trap, filtrate pump, and blower, 200 hp
8. Centrifuge for dewatering 38 tons/hr of 8 x 200 mesh refuse from concentrating table	1	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone-shaped basket of stainless steel for dewatering 8 x 200 mesh feed, individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body, 60 hp total

Area 5--Refuse Disposal

Item	No.	Description
1. Collecting conveyor for 124 tons/hr of 1-1/2 in. x 200 mesh refuse	1	Horizontal and inclined belt conveyor, 400 ft long with 24 in. wide belt, carbon steel, 15 hp
2. Refuse bin for truck loading	1	Storage bin, 16 ft wide x 26 ft long x 18 ft high on vertical sides, 13 ft deep pyramidal bottom with fast opening slides for truck loading
3. Trucks for transporting 124 tons/hr of 1-1/2 in. x 200 mesh refuse 1 mile from coal cleaning plant to disposal site	2	Off highway diesel electric dump truck, 100 ton payload, 100 yd^3 capacity, dump body for 1-1/2 in. x 200 mesh moist sluggish, abrasive refuse

(continued)

TABLE A-6 (continued)

Item	No.	Description
4. Refuse disposal site for 30 yr operation	1	"Dry" storage site with 25,000 acre capacity for layered refuse and earth
5. Bulldozer for spreading refuse and earth in layers at disposal site	1	Diesel bulldozer, 100 hp

Area 6--Clean Coal Storage

Item	No.	Description
1. Collecting conveyor for 685 tons/hr of 1-1/2 in. x 0 cleaned coal	1	Horizontal conveyor, 300 ft long with 48 in. wide belt, carbon steel, 20 hp
2. Transfer conveyors	2	Inclined conveyor, 200 ft long, 36 in. wide belt, with belt scale, carbon steel, 50 hp
3. Stacking conveyors for distributing coal along the tops of 2 parallel and adjacent wedge-shaped open piles, each of 150,000 tons	2	Elevated horizontal conveyor, 1,000 ft long with 1 traveling tripper, 36 in. wide belt, carbon steel, 40 hp
4. Hoppers under stockpile for reclaiming cleaned coal from stockpiles	20	Reclaiming hopper with 16 ft x 16 ft top opening, 4 ft deep pyramid, and 26 in. x 26 in. bottom opening, carbon steel
5. Pan feeders for withdrawing 1,350 tons/hr, 1-1/2 in. x 0 cleaned coal from reclaiming hoppers	20	Vibratory pan feeder with 30 in. wide x 48 in. long pan, carbon steel, 1.5 hp vibrator
6. Collecting conveyors for 1,350 tons/hr cleaned coal from pan feeders	2	Horizontal conveyor 1,000 ft long with 42 in. wide belt, carbon steel, 50 hp

(continued)

TABLE A-6 (continued)

	Item	No.	Description
7.	Tunnels for collecting conveyors	2	Steel reinforced concrete tunnel 8 ft wide x 6 ft deep x 1,000 ft long
8.	Tunnel sump pump	2	Centrifugal pump, 60 gpm, 30 ft head, carbon steel, 1 hp (1 spare)
9.	Transfer conveyor	1	Horizontal conveyor, 320 ft long with 42 in. wide belt, carbon steel, 15 hp
10.	Tunnel for transfer conveyor	1	Steel reinforced concrete tunnel 8 ft wide x 6 ft deep x 320 ft long
11.	Tunnel sump pump	1	Centrifugal pump, 60 gpm, 30 ft head, carbon steel, 1 hp (1 spare)
12.	Automatic sampling of coal from cleaning plant to stockpile	1	Automatic sampler of plate or similar type conforming with ASTM sampling requirements, primary sampling from 343 tons/hr, 1-1/2 in. x 0 coal from each of 2 transfer conveyors, combination of primary samples to a single sample of cleaning plant product
13.	Bulldozer for servicing stockpile	1	Diesel bulldozer, 100 hp

TABLE A-7. KVB COAL DESULFURIZATION PROCESS

MATERIAL BALANCE - BASE CASE

Stream No.	1	2	3	4	5	6	7
Description	Coal feed to reactor	Recycled gas stream	Makeup NO_2	Makeup O_2	Oxidizing gas to reactor	Coarse coal from reactor	Reactor off-gas
Total stream, tons/hr	593.0	1206.6	0.119	32.7	1238.8	399.2	1433.0
Stream components, tons/hr							
Coal	543.6					342.6	186.9
Pyritic S	19.1					0.248	0.135
Sulfate S	0.356					0.230	0.126
Organic S	9.0					5.8	3.2
H_2O	20.7	31.9			31.9	20.7	31.9
NO_2		103.9	0.119		104.0		104.0
O_2		3.1		32.0	34.5		3.1
N_2		1065.4		0.642	1066.0		1066.0
NO							
SO_2		2.1			2.1		21.3
$FeSO_4$, in coal						29.4	16.0
Na_2SO_3							
$NaHSO_3$							
$Ca(OH)_2$							
$Ca(SO_3)$							
NaOH							
$FeSO_4$, in solution							
Sulfate S, in solution							
Na_2SO_4							
$Fe(OH)_3$							
$Fe_2(SO_4)_3$							
$CaSO_4 \cdot 2H_2O$							
$CaSO_3 \cdot 2H_2O$							
$Na_3Fe_3(SO_4)_2(OH)_6$							
Binder							
Natural gas							
CaO							
Temperature, °F	55	302			302	200	200
Pressure, psig							
gpm							
aft^3/min							562,961

(continued)

TABLE A-7 (continued)

	8	9	10	11
	Water to venturi L/G = 10	Scrubber slurry outlet	Scrubber off-gas	Solution to venturi
1	1409.0	1616.5	1225.5	1519.5
2				
3				
4		186.9		
5		0.135		
6		0.126		
7		3.2		
8	1407.0	1406.9	31.9	1407.0
9			104.0	
10			3.1	
11			1066.0	
12				
13	2.0	3.0	20.2	
14		16.0		
15				109.3
16				
17				
18				
19				3.2
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	86	86	86	86
37			atm	
38	5,638	6,468		5,630
39				
40				

(continued)

TABLE A-7 (continued)

	12	13	14A	14B
	Scrubber solution outlet	Scrubber off-gas	Recycle gas	Bleed to flair
1	1542.0	1207.3	1206.6	0.783
2				
3				
4				
5				
6				
7				
8	1407.6	31.9	31.9	0.019
9		104.0	103.9	0.119
10		3.1	3.1	0.002
11		1066.0	1065.4	0.642
12				
13		2.1	2.1	0.001
14				
15	83.8			
16	50.4			
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	86	86	86	86
37		atm	atm	
38	5,632			
39				
40				

(continued)

TABLE A-7 (continued)

	15	16	17	20
	Thickener underflow	Thickener overflow	H_2O recycle	Effluent tank outlet
1	560.3	1056.1	1045.7	2102.1
2				
3				
4	186.9			
5	0.135			
6	0.126			
7	3.2			
8	353.6	1053.3	1045.7	2099.0
9				
10				
11				
12				
13	0.225	2.8		3.0
14	16.0			
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	86	86	55	
37				
38	1,415	4,215	4,184	8,399
39				
40				

(continued)

TABLE A-7 (continued)

	21	22	23	24
	Effluent bleed line	$Ca(OH)_2$ feed	Neutralizer tank outlet	Thickener underflow
1	693.0	179.7	1713.0	209.7
2				
3				
4				
5				
6				
7				
8	692.0	161.7	1569.4	175.4
9				
10				
11				
12				
13	1.0			
14				
15			114.4	5.1
16				
17		17.9		
18			29.1	29.1
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37				
38	2,769	647.0	6,279	702
39				
40				

(continued)

TABLE A-7 (continued)

	25 Thickener overflow	26 NaOH feed	27 Cyclone feed	28 Cyclone overflow
1	1503.2	16.3	942.0	655.8
2				
3				
4			186.9	
5			0.135	
6				
7			3.2	
8	1393.9	13.0	721.5	640.9
9				
10				
11				
12				
13			0.246	0.218
14			13.6	
15	109.3			
16				
17				
18				
19		3.2		
20			16.1	14.6
21			0.138	0.123
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36			200	200
37			60	
38	5,577	52	2,887	2,564
39				
40				

(continued)

TABLE A-7 (continued)

	29 Cyclone underflow	30 Wash water feed	31 Cyclone feed	32 Cyclone overflow
1	286.1	442.5	728.6	381.6
2				
3				
4	186.9		186.9	
5	0.135		0.135	
6				
7	3.2		3.2	
8	80.5	442.5	523.1	367.8
9				
10				
11				
12				
13	0.0[illegible]3		0.028	0.021
14	13.6			
15				
16				
17				
18				
19				
20	1.5		15.1	13.7
21	0.015		0.015	0.012
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	200	200	200	200
37			60	
38	322	1,771	2,093	1,472
39				
40				

(continued)

TABLE A-7 (continued)

	33	34	35	36
	Cyclone underflow	Cyclone overflow	Cyclone feed	Cyclone overflow
1	266.4	677.3	941.9	670.5
2				
3				
4	186.9		186.6	
5	0.135		0.135	
6				
7	3.2		3.0	
8	74.7	677.3	752.1	670.5
9				
10				
11				
12				
13	0.007			
14				
15				
16				
17				
18				
19				
20	1.4			
21	0.003			
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	200	200	200	200
37			60	
38	299	2,710	3,009	2,683
39				
40				

(continued)

TABLE A-7 (continued)

	37	38	39	40
	Cyclone underflow	NaOH feed to leach tank	Reaction tank feed	Fines Thickener overflow
1	271.2	6.2	272.0	673.6
2				
3				
4	186.6		185.1	
5	0.135		0.135	
6				
7	3.0		2.2	
8	81.3	3.1	84.5	667.0
9				
10				
11				
12				
13				0.007
14				
15				
16				
17				
18				
19		3.1		
20				
21				0.003
22				5.5
23				1.0
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	200	55	200	200
37				
38	326	13	338	2,669
39				
40				

(continued)

TABLE A-7 (continued)

	41	42	43	44
	Fines thickener underflow	Cyclone feed	Cyclone underflow	Cyclone feed
1	3.5	945.2	267.8	937.5
2				
3				
4		185.1	185.1	185.1
5		0.135	0.135	0.135
6				
7		2.2	2.2	2.2
8	3.5	757.7	80.3	750.0
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	200	200	200	200
37		60		60
38	14	3,032	322	3,001
39				
40				

(continued)

TABLE A-7 (continued)

	45	46	47	48
	Cyclone overflow	Cyclone underflow	Cyclone feed	Cyclone overflow
1	669.6	267.8	937.5	669.6
2				
3				
4		185.1	185.1	
5		0.135	0.135	
6				
7		2.2	2.2	
8	669.6	80.3	750.0	669.6
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	200	200	200	200
37			60	
38	2,680	322	3,001	2,680
39				
40				

(continued)

TABLE A-7 (continued)

	49	50	51	52
	Cyclone underflow	Wash water feed	Centrifuge feed	Centrifuge wash water
1	267.8	357.1	625.0	252.9
2				
3				
4	185.1		185.1	
5	0.135		0.135	
6				
7	2.2		2.2	
8	80.3	357.1	437.5	252.9
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	200	200	200	200
37			40	
38	322	1,429	1,751	1,012
39				
40				

(continued)

TABLE A-7 (continued)

	53	54	55	56
	Recycled centrate	Fine coal product	Classifier overflow	Classifier overflow
1	669.6	208.3	425.9	366.8
2				
3				
4		185.1		
5		0.135		
6				
7		2.2		
8	669.6	20.8	405.8	346.7
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20			20.0	19.9
21			0.035	0.215
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	200			
37				
38	2,680		1,624	1,387
39				
40				

(continued)

TABLE A-7 (continued)

	57	58	59	60
	Classifier underflow	Wash water feed	Classifier underflow	Coarse thickener feed
1	433.2	405.8	438.1	1328.3
2				
3				
4	342.6		342.6	342.4
5	0.248		0.248	0.248
6				
7	5.8		5.8	5.6
8	79.8	405.8	79.8	980.0
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20	4.5		9.5	
21	0.049		0.015	
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37				
38	319	1,624	319	3,921
39				
40				

(continued)

TABLE A-7 (continued)

	61	62	63	64
	Coarse thickener overflow	Coarse thickener underflow	NaOH feed	Reaction tank overflow
1	362.1	989.6	18.8	996.1
2				
3				
4		342.4		341.0
5		0.248		0.248
6				
7		5.6		4.1
8	338.6	641.3	9.4	650.8
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19			9.4	
20				
21	0.015			
22	16.7			
23	6.6			
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36			55	200
37				
38	1,355	2,566	38	2,604
39				
40				

(continued)

TABLE A-7 (continued)

	65	66	67	68
	Classifier overflow	Classifier overflow	Classifier underflow	Classifier overflow
1	335.7	900.2	431.7	335.7
2				
3				
4			341.0	
5			0.248	
6				
7			4.1	
8	335.7	900.2	86.3	335.7
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	200	200	200	200
37				
38	1,343	3,602	345	1,343
39				
40				

(continued)

TABLE A-7 (continued)

	69	70	71	72
	Classifier underflow	Classifier underflow	Wash water feed	Coarse coal centrifuge feed
1	431.7	431.7	143.9	575.6
2				
3				
4	341.0	341.0		341.0
5	0.248	0.248		0.248
6				
7	4.1	4.1		4.1
8	86.3	86.3	143.9	230.2
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	200	200	200	
37				
38	345	345	576	921
39				
40				

(continued)

TABLE A-7 (continued)

	73	74	75	76
	Centrifuge wash water feed	Recycle centrate	Coarse coal product	Combined leachate feed
1	143.9	335.7	383.7	2268.2
2				
3				
4			341.0	
5			0.248	
6				
7			4.1	
8	143.9	335.7	38.3	2160.1
9				
10				
11				
12				
13				0.225
14				
15				5.1
16				
17				
18				
19				
20				34.5
21				0.356
22				22.2
23				7.6
24				
25				
26				37.8
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	200	200		200
37				
38	576	1,343		8,643
39				
40				

(continued)

TABLE A-7 (continued)

	77	78	79	80
	50% NaOH feed	20% lime feed	O_2 feed	Neutralizer effluent
1	0	15.5	4.5	2990.3
2				
3				
4		12.4		
5				
6				
7				
8	0			2869.1
9				
10			4.4	
11			0.092	
12				
13				
14				
15				7.5
16				
17		3.1		
18				
19	0			
20				
21				
22				22.6
23				7.9
24				5.0
25				49.0
26				
27				29.0
28				
29				
30				
31				
32				
33				
34				
35				
36				200
37				11,480
38	38	50		
39				
40				

(continued)

TABLE A-7 (continued)

	81	82	83	84
	Pond settled solids	Pond water recycle	Fine coal wash water	Coarse coal wash water
1	202.0	2788.3	610.1	287.8
2				
3				
4				
5				
6				
7				
8	80.8	2788.3	610.1	287.8
9				
10				
11				
12				
13				
14				
15	7.5			
16				
17				
18				
19				
20				
21				
22	22.6			
23	7.9			
24	5.0			
25	49.0			
26				
27	29.0			
28				
29				
30				
31				
32				
33				
34				
35				
36		55	55	55
37				
38		11,156	2,441	1,152
39				
40				

(continued)

TABLE A-7 (continued)

	85	86	87	88
	Water to NaOH preparation	Water to lime slaker	Raw water makeup	Slaked lime
1	9.7	179.3	192.9	105.4
2				
3				
4				
5				
6				
7				
8	9.7	179.3	192.9	84.3
9				
10				
11				
12				
13				
14				
15				
16				
17				21.0
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	55	55	55	
37				
38	39	697	752	338
39				
40				

(continued)

TABLE A-7 (continued)

	89	90	91	92
	Raw lime	NaOH feed to mix tank	NaOH	O_2
1	15.9	6.5	31.4	37.3
2				
3				
4				
5				
6				
7				
8		3.2	15.7	
9				
10				36.5
11				0.734
12				
13				
14				
15				
16				
17				
18				
19		3.2	15.7	
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30	15.9			
31				
32				
33				
34				
35				
36				
37				
38		13	92	
39				
40				

(continued)

TABLE A-7 (continued)

	93	94	95	96
	Binder solution	Coarse coal bleed	Feed to agglomeration	Steam from dryer
1	9.4	57.5	265.9	18.4
2				
3				
4		51.1	236.2	
5		0.038	0.173	
6				
7		0.615	2.8	
8	4.7	5.7	26.5	18.4
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28	4.7			
29				
30				
31				
32				
33				
34				
35				
36				
37				
38	20			
39				
40				

(continued)

TABLE A-7 (continued)

	97	98	99	100
	Pellet product	Coarse coal product	Clean coal product	Natural gas
1	256.8	342.2	598.9	0.067
2				
3				
4	236.2	294.4	530.6	
5	0.173	0.286	0.459	
6	0.236		0.236	
7	2.8	3.3	6.3	
8	12.8	44.1	56.9	
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28	4.5		4.5	
29				0.067
30				
31				
32				
33				
34				
35				
36				
37				
38				
39				50
40				

(continued)

TABLE A-7 (continued)

	101	102	103	104
	Cooling H_2O	Gas reheat steam	Water heater steam	Water heater steam
1	0.30	45.5	81.0	65.4
2				
3				
4				
5				
6				
7				
8	0.30	45.5	81.0	65.4
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36		434	434	434
37		345	345	345
38	1.2			
39				
40				

(continued)

TABLE A-7 (continued)

	105	106	107	108
	Water heater steam	Water heater steam	Steam	Steam
1	46.3	74.3	6.5	6.5
2				
3				
4				
5				
6				
7				
8	46.3	74.3	6.5	6.5
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	434	434	434	434
37	345	345	345	345
38				
39				
40				

TABLE A-8. KVB COAL DESULFURIZATION PROCESS

EQUIPMENT LIST - BASE CASE (5% S COAL)

Area 1--Raw Material Handling and Preparation

Item	No.	Description
1. Conveyor, coal unloading	1	1000 tons/hr, 42-in. belt, 500 ft long, 100-hp motor, 2 fixed trippers, CS
2. Conveyor, coal stacker	2	1000 tons/hr, 42-in. belt, 968 ft long, 40-hp motor, 1 traveling tripper, CS
3. Hopper, pile reclaim	20	13-ft x 13-ft top opening, 3-ft-deep pyramid, with 22-in. x 22-in. bottom opening, CS
4. Feeders, vibrating pan	20	120 tons/hr, 24 in. wide, 42-in.-long pan, with 1.5-hp vibrator, CS
5. Conveyor, coal transfer	2	593 tons/hr, 42-in. belt, 970 ft long, 25-hp motor, CS
6. Tunnel, conveyor	2	7 ft wide, 6 ft deep, 970 ft long, steel reinforced concrete
7. Pump, tunnel sump	2	60-gpm, 30-ft head, centrifugal, 1-hp motor, CS
8. Conveyor, coal transfer	1	593 tons/hr, 42-in. belt, 320 ft long, 5-hp motor, CS
9. Tunnel, conveyor	1	7 ft wide, 6 ft deep, 320 ft long, steel reinforced concrete
10. Pump, tunnel sump	1	60-gpm, 30-ft head, centrifugal, 1-hp motor, CS
11. Conveyor, crusher feed	1	593 tons/hr, 42-in. belt, 565 ft long, 100-hp motor, totally enclosed, CS
12. Sampler, coal	1	Automatic coal sampler
13. Bin, coal surge	2	3600 ft^3, 15 ft wide, 15 ft long, 16 ft high, 13-ft-deep pyramid bottom, closed top, CS

(continued)

TABLE A-8 (continued)

	Item	No.	Description
14.	Feeder, weigh belt	2	297 tons/hr, 42-in. belt, 10 ft long, 2-hp motor, CS
15.	Crusher, coal	2	297 tons/hr, double roll type, 36-in.-diameter rolls, 2 each 25-hp motors, totally enclosed, CS
16.	Screen, coal	2	297 tons/hr, 119 ft^2 area, 7 ft x 17 ft, flip flow vibrating screen deck, 40-hp motor, CS
17.	Crusher, coal	2	173 tons/hr, double roll type, 30-in.-diameter rolls, 2 each 20-hp motors, totally enclosed, CS
18.	Conveyor, reactor area feed	1	593 tons/hr, 42-in. belt, 560 ft long, 100-hp motor, with 4 fixed trippers, totally enclosed, CS
19.	Pump, NO_2 unloading	2	70-gpm, 415-ft head, positive displacement, 15-hp motor, 316 SS
20.	Tank, NO_2 storage	1	17,600 gal, 10-ft-diameter, 30 ft long, horizontal type, 150-psig operating pressure, 316 SS
21.	Pump, binder unloading	2	40-gpm, 50-ft head, centrifugal, 2-hp motor, CS
22.	Pump, binder storage	1	887,000 gal, 55-ft-diameter, 50 ft high, flat bottom, closed top, CS
23.	Pump, binder feed	2	20-gpm, 200-ft head, centrifugal, 5-hp motor, CS
24.	Pump, NaOH unloading	2	55-gpm, 40-ft head, centrifugal, 1.5-hp motor, neoprene lined CS
25.	Tank, NaOH storage	4	994,000 gal, 59-ft-diameter, 50 ft high, flat bottom closed top, neoprene lined CS
26.	Pump, NaOH feed	2	13-gpm, 100-ft head, centrifugal, 1-hp motor, neoprene lined CS

(continued)

TABLE A-8 (continued)

Item	No.	Description
27. Pump, NaOH feed	2	38-gpm, 100-ft head, centrifugal, 3-hp motor, neoprene lined CS
28. Pump, NaOH feed	2	28-gpm, 100-ft head, centrifugal, 3-hp motor, neoprene lined CS
29. Pump, NaOH transfer	2	13-gpm, 100-ft head, centrifugal, 1-hp motor, neoprene lined CS
30. Tank, 20% NaOH mix	1	25,470 gal, 17-ft-diameter, 15 ft high, flat bottom, closed top, neoprene lined CS
31. Agitator, NaOH mix tank	1	15-hp, neoprene coated CS
32. Pump, 20% NaOH feed	2	52-gpm, 100-ft head, centrifugal, 3-hp motor, neoprene lined CS
33. Hoist, car shaker	1	2,000 lb capacity, 15-hp motor
34. Shaker, car	1	Railroad, trackside vibrator, 20-hp
35. Puller, car	1	Railroad car puller with base, wire rope, 25-hp motor, 5-hp return motor
36. Hopper, lime unloading	1	94 ft^3, 8-ft 4-in. x 8-ft 4-in. top opening, 3-ft-deep pyramid, with 2-ft 4-in. x 2-ft 4-in. bottom opening
37. Feeder, lime vibrating	1	210 tons/hr, 42 in. wide, 5 ft long pan, 2.5-hp vibrator, CS
38. Conveyor, lime unloading	1	210 tons/hr, 24-in. belt, 10 ft long, 2.5-hp motor, CS
39. Conveyor, lime unloading	1	210 tons/hr, 24-in. belt, 381 ft long, 25-hp motor, totally enclosed, CS
40. Tunnel, conveyor	1	6 ft wide, 6 ft high, 70 ft long, steel reinforced concrete
41. Pump, tunnel sump	1	20-gpm, 20-ft head, centrifugal, 0.5-hp motor, CS

(continued)

TABLE A-8 (continued)

Item	No.	Description
42. Silo, lime storage	1	430,000 ft^3, 74-ft-diameter, 100 ft high, cone bottom, closed top, CS
43. Feeder, weigh belt	1	22 tons/hr, 12-in. belt, 10 ft long, 0.5-hp motor, CS
44. Conveyor, slaker feed	1	22 tons/hr, 12-in. belt, 40 ft long, 0.75-hp motor, CS
45. Slaker, lime	1	105.5 tons/hr of 20% slaked slurry product, 20 ft x 43 ft x 9.5 ft high, 2-hp motor on rake drive, 30-hp mixer
46. Pump, lime slaker product	2	338-gpm, 100-ft head, centrifugal, 20-hp motor, neoprene lined CS
47. Tank, 20% lime feed	1	25,470 gal, 17-ft-diameter, 15 ft high, flat bottom, closed top, neoprene lined CS
48. Agitator, 20% lime feed tank	1	10-hp, neoprene coated CS
49. Pump, 20% lime feed	2	50-gpm, 100-ft head, centrifugal, 3-hp motor, neoprene lined CS
50. Tank, 10% lime feed	1	322,400 gal, 38-ft-diameter, 38 ft high, flat bottom, closed top, neoprene lined CS
51. Agitator, 10% lime feed tank	1	20-hp, neoprene coated CS
52. Pump, 10% lime feed	2	647-gpm, 100-ft head, centrifugal, 30-hp motor, neoprene lined CS

Area 2--Sulfur Oxidation

Item	No.	Description
1. Bin, reactor feed	4	5670 ft^3, 19-ft-diameter, 20 ft high, cone bottom, closed top, CS

(continued)

TABLE A-8 (continued)

Item	No.	Description
2. Feeder, weigh belt	4	149 tons/hr, 24-in. belt, 15 ft long, 1-hp motor, CS
3. Reactor, fluidized bed	4	22.3-ft-diameter, 51-ft high side, cone bottom, cone top, 1 atmosphere operating pressure, 316 SS
4. Fan, scrubber forced draft	4	140,740 aft^3/min at 200°F, ΔP 15-in. H_2O, 450-hp motor, 316 SS
5. Fan, recirculating	4	140,740 aft^3/min at 200°F, ΔP 15-in. H_2O, 450-hp motor, 316 SS
6. Heater, oxidizing gas	4	8,080 ft^2 area, 316 SS
7. "Scrubber", vent gas combustion	1	10-ft x 10-ft natural gas fired NO_xIDIZER, 10-hp blower, 35-ft of stack, CS

Area 3--Reactor Off-Gas Cleaning

Item	No.	Description
1. Scrubber, particulate	4	Venturi, 14.8-ft-diameter, 52 ft high, with mist eliminator, 316 SS
2. Thickener, fine coal	4	13 ft wide, 22 ft long, 21 ft high, inclined plate gravity settler-thickener with increased volume sludge compartment, 1-hp picket-fence rake
3. Pump, thickener underflow	6	354-gpm, 160-ft head, centrifugal, 40-hp motor, neoprene lined CS
4. Tank, thickener overflow	4	6600 gal, 7.5-ft-diameter, 20 ft high, flat bottom, neoprene lined CS
5. Pump, venturi feed	6	2100-gpm, 100-ft head, centrifugal, 100-hp motor, neoprene lined CS

(continued)

TABLE A-8 (continued)

Item	No.	Description
6. Absorber, SO_2	4	Venturi, 14.8-ft-diameter, 52 ft high, with mist eliminator, 316 SS
7. Tank, effluent surge	4	16,100 gal, 14-ft-diameter, 14 ft high, cone bottom, neoprene lined CS
8. Agitator, effluent surge tank	4	10-hp, neoprene coated CS
9. Pump, effluent	6	1570-gpm, 100-ft head, centrifugal, 75-hp motor, neoprene lined CS
10. Thickener, absorber	4	13 ft wide, 22 ft long, 21 ft high, inclined plate gravity settler-thickener with increased volume sludge compartment, 1-hp picket-fence rake
11. Pump, thickener underflow	6	176-gpm, 100-ft head, centrifugal, 10-hp motor, neoprene lined CS
12. Tank, thickener overflow neutralizer	4	4280 gal, 9-ft-diameter, 9 ft high, cone bottom, neoprene lined CS
13. Agitator, thickener	4	5-hp, neoprene coated CS
14. Pump, thickener underflow	6	1408-gpm, 100-ft head, centrifugal, 75-hp motor, neoprene lined CS
15. Fan, absorber forced draft	4	140,740 aft^3/min at 200°F, ΔP 15-in. H_2O, 450-hp motor, 316 SS

Area 4--Fine Coal Leaching

Item	No.	Description
1. Tank, water leach	4	3600 gal, 8.5-ft-diameter, 8.5 ft high, cone bottom, closed top, neoprene lined CS
2. Agitator, water leach tank	4	10-hp, neoprene coated CS

(continued)

TABLE A-8 (continued)

Item	No.	Description
3. Pump, cyclone feed	6	722-gpm, 260-ft head, centrifugal, 125-hp motor, CS
4. Cyclone, water leach	36	90-gpm, 6-in.-diameter, heavy duty cyclone, 100 psig operating pressure, high density gum rubber-lined cast iron and steel
5. Tank, cyclone underflow	4	1614 gal, 6.5-ft-diameter, 6.5 ft high, cone bottom, closed top, neoprene lined CS
6. Agitator, cyclone underflow tank	4	5-hp, neoprene coated CS
7. Heater, process water	4	178 ft^2 area, CS
8. Pump, cyclone feed	6	523-gpm, 260-ft head, centrifugal, 100-hp motor, CS
9. Cyclone, water leach	24	90-gpm, 6-in.-diameter,heavy duty cyclone, 100 psig operating pressure, high density gum rubber-lined cast iron and steel
10. Tank, cyclone underflow	4	3600 gal, 8.5-ft-diameter, 8.5 ft high, flat bottom, closed top, neoprene lined CS
11. Agitator, cyclone underflow tank	4	10-hp, neoprene coated CS
12. Pump, cyclone feed	6	752-gpm, 260-ft head, centrifugal, 125-hp motor, CS
13. Cyclone, caustic leach	36	90-gpm, 6-in.-diameter, heavy duty cyclone 100 psig operating pressure, high density gum rubber-lined cast iron and steel
14. Tank, cyclone underflow	4	850 gal, 5.25-ft-diameter, 5.25 ft high, flat bottom, closed top, neoprene lined CS
15. Agitator, cyclone underflow tank	4	10-hp, neoprene coated CS

(continued)

TABLE A-8 (continued)

Item	No.	Description
16. Pump, slurry transfer	6	85-gpm, 100-ft head, centrifugal, 15-hp motor, neoprene lined CS
17. Thickener, fine coal	4	10 ft wide, 19 ft long, 21 ft high, inclined plate gravity settler-thickener with increased volume sludge compartment, 1-hp picket-fence rake
18. Pump, thickener underflow	6	3.5-gpm, 100-ft head, centrifugal, 0.25-hp motor, neoprene lined CS
19. Tank, thickener overflow	4	2000 gal, 7-ft-diameter, 7 ft high, flat bottom, neoprene lined CS
20. Pump, thickener overflow	6	667-gpm, 100-ft head, centrifugal, 30-hp motor, neoprene lined CS
21. Tank, leach mix	4	7800 gal, 11-ft-diameter, 11 ft high, cone bottom, closed top, neoprene lined CS
22. Agitator, leach mix tank	4	5-hp, neoprene coated CS
23. Pump, cyclone feed	6	758-gpm, 260-ft head, centrifugal, 125-hp motor, CS
24. Cyclone, water wash	36	90-gpm, 6-in.-diameter, heavy duty cyclone, 100 psig operating pressure, high density gum rubber-lined cast iron and steel
25. Tank, cyclone underflow	4	3800 gal, 8.5-ft-diameter, 9 ft high, cone bottom, closed top, neoprene lined CS
26. Agitator, cyclone underflow tank	4	10-hp, neoprene coated CS
27. Pump, cyclone feed	6	758-gpm, 260-ft head, centrifugal, 125-hp motor, CS

(continued)

TABLE A-8 (continued)

Item	No.	Description
28. Cyclone, water wash	36	90-gpm, 6-in.-diameter, heavy duty cyclone, 100 psig operating pressure, high density gum rubber-lined cast iron and steel
29. Tank, cyclone underflow	4	3800 gal, 8.5-ft-diameter, 9 ft high, cone bottom, closed top, neoprene lined CS
30. Agitator, cyclone underflow tank	4	10-hp, neoprene coated CS
31. Pump, cyclone feed	6	758-gpm, 260-ft head, centrifugal, 125-hp motor, CS
32. Cyclone, wash water	36	90-gpm, 6-in.-diameter, heavy duty cyclone, 100 psig operating pressure, high density gum rubber-lined cast iron and steel
33. Tank, cyclone underflow	4	1270 gal, 6-ft-diameter, 6 ft high, cone bottom, closed top, neoprene lined CS
34. Agitator, cyclone underflow tank	4	10-hp, neoprene coated CS
35. Pump, centrifuge feed	6	437-gpm, 100-ft head, centrifugal, 30-hp motor, neoprene lined CS
36. Heater, process water	4	144 ft^2 area, CS
37. Heater, process water	4	102 ft^2 area, CS
38. Centrifuge, fine coal	4	44-in.-diameter, 132 in. long, continuous screen bowl type, 200-hp motor
39. Tank, centrate	4	2000 gal, 7-ft-diameter, 7 ft high, cone bottom, closed top, CS
40. Pump, centrate return	6	670-gpm, 100-ft head, centrifugal, 30-hp motor, CS
41. Conveyor, centrifuge product	1	209 tons/hr, 30-in. belt, 160 ft long, 5-hp motor, CS

(continued)

TABLE A-8 (continued)

Item	No.	Description
42. Conveyor, centrifuge product	1	209 tons/hr, 30-in. belt, 180 ft long, 5-hp motor, CS
43. Sampler, coal	1	Automatic coal sampler
44. Elevator, bucket	2	105 tons/hr, 40 ft high, 16-in. x 8-in. x 11-3/4-in. continuous buckets, belt drive, 7.5-hp motor, CS

Area 5--Coarse Coal Leaching

Item	No.	Description
1. Dewaterer, water leach	4	100 tons/hr, single screw spiral dewaterer, 54-in.-diameter flights, 34-ft tube length, 40-hp motor, closed top, CS
2. Pump, overflow	6	347-gpm, 100-ft head, centrifugal, 20-hp motor, neoprene lined CS
3. Dewaterer, water leach	4	100 tons/hr, single screw spiral dewaterer, 54-in.-diameter flights, 34-ft tube length, 40-hp motor, closed top, CS
4. Pump, dewaterer overflow	6	406-gpm, 100-ft head, centrifugal, 20-hp motor, neoprene lined CS
5. Heater, process water	4	163 ft^2 area, CS
6. Tank, caustic leach	4	10,000 gal, 12-ft-diameter, 12 ft high, cone bottom, closed top, neoprene lined CS
7. Agitator, caustic leach tank	4	10-hp, neoprene coated CS
8. Pump, thickener feed	6	980-gpm, 100-ft head, centrifugal, 60-hp motor, neoprene lined CS
9. Thickener, coarse coal	4	10 ft wide, 19 ft long, 21 ft high, inclined plate gravity settler-thickener with increased volume sludge compartment, 1-hp picket-fence rake

(continued)

TABLE A-8 (continued)

Item	No.	Description
10. Pump, thickener underflow	6	641-gpm, 100-ft head, centrifugal, 50-hp motor, neoprene lined CS
11. Tank, thickener overflow	4	975 gal, 5.5-ft-diameter, 5.5 ft high, flat bottom, closed top, neoprene lined CS
12. Pump, thickener overflow	6	339-gpm, 100-ft head, centrifugal, 20-hp motor, neoprene lined CS
13. Tank, caustic leach	4	6460 gal, 10-ft-diameter, 11 ft high, flat bottom, closed top, neoprene lined CS
14. Agitator, caustic leach tank	4	5-hp, neoprene coated CS
15. Dewaterer, water wash	4	100 tons/hr, single screw spiral dewaterer, 54-in.-diameter flights, 34-ft tube length, 40-hp motor, closed top, CS
16. Pump, dewaterer overflow	6	900-gpm, 100-ft head, centrifugal, 40-hp motor, neoprene lined CS
17. Dewaterer, water wash	4	100 tons/hr, single screw spiral dewaterer, 54-in.-diameter flights, 34-ft tube length, 40-hp motor, closed top, CS
18. Pump, dewaterer overflow	6	336-gpm, 100-ft head, centrifugal, 15-hp motor, neoprene lined CS
19. Dewaterer, water wash	4	100 tons/hr, single screw spiral dewaterer, 54-in.-diameter flights, 34-ft tube length, 40-hp motor, closed top, CS
20. Pump, dewaterer overflow	6	336-gpm, 100-ft head, centrifugal, 15-hp motor, neoprene lined CS
21. Tank, water wash	4	1070 gal, 5.5-ft-diameter, 6 ft high, cone bottom, closed top, neoprene lined CS
22. Agitator, water wash tank	4	10-hp, neoprene coated CS

(continued)

TABLE A-8 (continued)

Item	No.	Description
23. Heater, process water	4	58 ft^2 area, CS
24. Pump, centrifuge feed	6	230-gpm, 100-ft head, centrifugal, 25-hp motor, neoprene lined CS
25. Heater, process water	4	58 ft^2 area, CS
26. Centrifuge, coarse coal	4	230-gpm, continuous oscilating bowl, 25-hp motor and 5-hp motor
27. Tank, centrate	4	1070 gal, 5.5-ft-diameter, 6 ft high, flat bottom, closed top, CS
28. Pump, centrate return	6	336-gpm, 100-ft head, centrifugal, 15-hp motor, CS
29. Conveyor, centrifuge product	1	384 tons/hr, 30-in. belt, 160 ft long, 5-hp motor, CS
30. Sampler, coal	1	Automatic coal sampler
31. Conveyor, coarse coal bleed	1	56 tons/hr, 18-in. belt, 50 ft long, 5-hp motor, CS
32. Conveyor, stacker feed	1	596 tons/hr, 42-in. belt, 715 ft long, 50-hp motor, CS
33. Elevator, coal dryer feed	8	100 tons/hr, 96 ft high, 24-in. x 8-in. x 11-3/4-in. continuous buckets, double chain drive, 20-hp motor, CS
34. Elevator, coal mix bin feed	2	134 tons/hr, 40 ft high, 20-in. x 8-in. x 11-3/4-in. continuous buckets, belt drive, 7.5-hp motor, CS

Area 6--Product Agglomeration and Handling

Item	No.	Description
1. Bin, coal mix	1	1725 ft^3, 13-ft-diameter, 13 ft high, cone bottom, CS

(continued)

TABLE A-8 (continued)

Item	No.	Description
2. Feeder, coal	1	266 tons/hr, 30-in. belt, 5 ft long, 1.5-hp motor, CS
3. Conveyor, coal transfer	1	266 tons/hr, 30-in. belt, 200 ft long, 40-hp motor, 11 fixed trippers, CS
4. Pelletizing plants	11	25 tons/hr package pelletizing plants including 23-ft-diameter pan pelletizer, dryers and all support systems
5. Conveyor, pelletizer product	1	125 tons/hr, 24-in. belt, 185 ft long, 2-hp motor, CS
6. Conveyor, pelletizer product	1	125 tons/hr, 24-in. belt, 130 ft long, 2-hp motor, CS
7. Conveyor, stacker	2	596 tons/hr, 42-in. belt, 968 ft long, 25-hp motor, traveling tripper, CS
8. Hopper, pile reclaim	20	13-ft x 13-ft top opening, 3-ft-deep pyramid, with 22-in. x 22-in. bottom opening, CS
9. Feeders, vibrating pan	20	120 tons/hr, 24 in. wide, 42-in. long pan, 1.5-hp vibrator, CS
10. Conveyor, coal transfer	2	1000 tons/hr, 42-in. belt, 970 ft long, 40-hp motor, CS
11. Tunnel, conveyor	2	7 ft wide, 6 ft deep, 970 ft long, steel reinforced concrete
12. Tunnel, conveyor	1	7 ft wide, 6 ft deep, 320 ft long, steel reinforced concrete
13. Pump, tunnel sump	3	60-gpm, 30-ft head, centrifugal, 1-hp motor, CS

(contineud)

TABLE A-8 (continued)

Area 7--Leach Solution Neutralization and Water Handling

	Item	No.	Description
1.	Tank, neutralizer stage 1	4	25,600 gal, 16-ft-diameter, 17 ft high, flat bottom, closed top, neoprene lined CS
2.	Agitator, neutralizer stage 1 tank	4	10-hp, neoprene coated CS
3.	Tank, neutralizer, stage 2	4	8500 gal, 11-ft-diameter, 12 ft high, flat bottom, closed top, neoprene lined CS
4.	Agitator, neutralizer stage 2 tank	4	10-hp, neoprene coated CS
5.	Tank, neutralizer stage 3	4	8500 gal, 11-ft-diameter, 12 ft high, flat bottom, closed top, neoprene lined CS
6.	Agitator, neutralizer stage 3 tank	4	10-hp, neoprene coated CS
7.	Tank, neutralizer stage 4	4	8500 gal, 11-ft-diameter, 12 ft high, flat bottom, closed top, neoprene lined CS
8.	Agitator, neutralizer stage 4 tank	4	10-hp, neoprene coated CS
9.	Pump, pond feed	2	11,480-gpm, 300-ft head, centrifugal, 1750-hp motor, neoprene lined CS
10.	Pipeline, pond feed	2	30-in.-diameter, 5280 ft long, rubber-lined CS
11.	Pump, pond return	2	11,156-gpm, 300-ft head, centrifugal, 1500-hp motor, CS
12.	Pipeline, pond return	1	30-in.-diameter, 5280 ft long, CS

(continued)

TABLE A-8 (continued)

Item	No.	Description
13. Tank, recycle water	1	5,400,000 gal, 150-ft-diameter, 41 ft high, flat bottom, CS
14. Pump, water feed	2	4184-gpm, 100-ft head, centrifugal, 200-hp motor, CS
15. Pump, water feed	2	697-gpm, 100-ft head, centrifugal, 30-hp motor, CS
16. Pump, water feed	2	39-gpm, 100-ft-head, centrifugal, 2-hp motor, CS
17. Pump, water feed	2	1152-gpm, 100-ft head, centrifugal, 50-hp motor, CS
18. Pump, water feed	2	2441-gpm, 100-ft head, centrifugal, 125-hp motor, CS
19. Pump, water feed	2	1624-gpm, 100-ft head, centrifugal, 75-hp motor, CS
20. Pump, water feed	2	1771-gpm, 100-ft head, centrifugal, 75-hp motor, CS
21. Pump, makeup water	2	752-gpm, 100-ft head, centrifugal, 40-hp motor, CS

Area 8--Settling Pond

Item	No.	Description
1. Pond	1	932 acres, 25.58 ft deep, with clay lining

TABLE A-9. TRW GRAVICHEM COAL DESULFURIZATION PROCESS

MATERIAL BALANCE - BASE CASE

TABLE A-9 (continued)

	Stream No.	1	2	3	4	5	6	7
	Description	Crushed coal	Heated coal feed	Leach solution feed	Mixed coal slurry	Slurry to heavy media cyclones	Sink coal slurry	Float coal slurry
1	Total stream, tons/hr	593.0	629.0	1736.6	2353.6	2353.6	1151.6	1202.0
2								
3	Stream components, tons/hr							
4	Coal	448.1	448.1		448.1	448.1	266.0	182.1
5	Pyrite, S	19.1	19.1		14.7	14.7	14.6	0.100
6	Sulfate, S (in coal)	0.356	0.356					
7	Organic, S	9.0	9.0		9.	9.0	8.5	0.554
8	Ash	95.4	95.4		93.4	93.4	89.8	3.5
9	H_2O	20.7	56.8	1182.6	1236.3	1236.3	533.7	702.5
10	Sulfate, S (in solution)				0.356	0.356	0.153	0.203
11	$FeSO_4$			38.2	95.1	95.1	41.1	54.0
12	$Fe_2(SO_4)_3$			442.8	365.2	365.2	157.6	207.6
13	H_2SO_4			72.9	90.2	90.2	38.9	51.2
14	S				0.943	0.943	0.943	0
15	O_2							
16	$Ca(OH)_2$							
17	$CaSO_4 \cdot 2H_2O$							
18	Acetone (liquid)							
19	Acetone (gas)							
20	$Fe(OH)_2$							
21	$Fe(OH)_3$							
22	CaO							
23								
24								
25								
26								
27								
28								
29								
30								
31								
32								
33								
34								
35								
36								
37	Temperature, °F	55	215	215	215	164	164	164
38	Pressure, psig							
39	Gpm			4,891	5,144	5,144	2,221	2,923
40	Aft^3/min							

(continued)

(continued)

TABLE A-9 (continued)

	8	9	10	11
	Leach solution filtrate	Wash solution feed	Wash solution filtrate	Filtered coal
1	923.9		211.8	
2				
3				
4				182.1
5				0.100
6				
7				0.554
8				3.5
9	639.1	183.5	183.5	91.7
10	0.185		0.018	
11	49.1		4.8	
12	188.8		18.7	
13	46.6		4.6	
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	160	160	160	160
38				
39	2,650	≈744	≈744	
40				

(continued)

TABLE A-9 (continued)

	12	13	14	15
	Wash solution feed	Coal slurry feed to filter	Wash solution feed	Filtered coal
1				
2				
3				
4		182.1		182.1
5		0.100		0.100
6				
7		0.554		0.554
8		3.5		3.5
9	183.5	275.2	183.5	91.7
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	160	160	160	160
38				
39	≈744	≈1,112	≈744	
40				

(continued)

TABLE A-9 (continued)

	16	17	18	19
	Wash solution feed	Coal slurry feed to filter	Wash water feed	Float coal product
1			183.5	278.0
2				
3				
4		182.1		182.1
5		0.100		0.100
6				
7		0.554		0.554
8		3.5		3.5
9	183.5	275.2	183.5	91.7
10				
11				0.007
12				0.018
13				0.006
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	160	160	160	160
38				
39	744	1,112	734	
40				

(continued)

TABLE A-9 (continued)

	20	21	22	23
	Reactor gas feed	Reactor vent gas	Reacted coal slurry	Flash steam
1	5.9	Nil	1173.1	29.9
2				
3				
4			266.0	
5			0.383	
6				
7			8.5	
8			83.2	
9		Nil	547.4	29.9
10			0.153	
11			4.6	
12			236.7	
13			21.8	
14			4.0	
15	5.9	Nil		
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37			250	219
38	50		50	2.3
39			2,238	
40				

(continued)

TABLE A-9 (continued)

	24	25	26	27
	Coal slurry to cooler	Compressed oxygen feed	Reactor oxygen feed	Regenerator oxygen feed
1	1143.2	7.0	5.9	1.0
2				
3				
4	266.0			
5	0.383			
6				
7	8.5			
8	83.2			
9	517.5			
10	0.153			
11	4.6			
12	236.7			
13	21.8			
14	4.0			
15		7.0	5.9	1.0
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	219			
38		50	50	35
39	2,119			
40				

(continued)

TABLE A-9 (continued)

	28	29	31	32
	Regenerator vent gas to reactor	High pressure steam to reactor	Coal slurry feed to filter	Leach solution filtrate
1	Nil	10.6	1143.2	602.6
2				
3				
4			266.0	
5			0.383	
6				
7			8.5	
8			83.2	
9		10.6	517.5	400.1
10			0.153	0.118
11			4.6	3.5
12			236.7	181.9
13			21.8	16.8
14			4.0	
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37		422	160	160
38		300		
39			2,119	1,638
40				

(continued)

TABLE A-9 (continued)

	33 Wash water feed	34 Wash solution filtrate	35 Filtered coal	36 Acetone feed to wash tank
1	252.4	252.4	540.5	364.8
2				
3				
4			266.0	
5			0.383	
6				
7			8.5	
8			83.2	
9	252.4	200.6	169.2	
10		0.030	0.005	
11		0.916	0.162	
12		46.5	8.2	
13		4.3	0.761	
14			4.0	
15				
16				
17				
18				364.8
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	160	160	160	85
38				
39	1,010	812		1,846
40				

(continued)

TABLE A-9 (continued)

	37 Acetone/coal slurry to cooler	38 Acetone/coal slurry to filter No. 5	39 Acetone wash feed	40 Filtered coal to dryer
1	905.3	905.3	153.1	553.5
2				
3				
4	266.0	266.0		266.0
5	0.383	0.383		0.383
6				
7	8.5	8.5		8.5
8	83.2	83.2		83.2
9	169.2	169.2		60.3
10	0.005	0.005		
11	0.162	0.162		0.001
12	8.2	8.2		0.065
13	0.761	0.761		0.006
14	4.0	4.0		0.724
15				
16				
17				
18	364.8	364.8	153.1	134.2
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	130	85	85	85
38				
39	2,525	2,525	775	
40				

(continued)

TABLE A-9 (continued)

	41	42	43	44
	Acetone solution filtrate	Wash solution to evaporator	Leachate to regenerator preheater	Leachate to regenerator
1	504.9	464.3	841.5	841.5
2				
3				
4				
5				
6				
7				
8				
9	108.8	384.2	582.1	582.1
10	0.005	0.048		
11	0.161	5.7	44.8	44.8
12	8.1	65.3	172.0	172.0
13	0.755	8.9	42.5	42.5
14	3.2			
15				
16				
17				
18	383.7			
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	85	160	160	244
38				
39	2,379	1,557	2,422	2,422
40				

(continued)

TABLE A-9 (continued)

	45	46	47	48
	Regenerated leachate to recycle tank	Sulfuric acid makeup	Leach solution from evaporator	Dilution water to leachate recycle tank
1	842.4	10.4	271.7	6.1
2				
3				
4				
5				
6				
7				
8				
9	583.1		191.6	6.1
10			0.048	
11	26.9		5.7	
12	195.6		65.3	
13	36.7	10.4	8.9	
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	250	55	181	55
38				
39	2,414	21	786	25
40				

(continued)

TABLF A-9 (continued)

	49	50	51	52
	Leachate bleed to neutralizer	Makeup $FeSO_4 \cdot 7H_2O$ (copperas)	Leach solution feed	Cleaned coal product
1	82.3	3.5	1736.6	419.6
2				
3				
4				266.0
5				0.383
6				
7				8.5
8				83.2
9	57.0	1.5	1182.6	60.3
10	0.055			
11	4.3	1.9	38.2	0.001
12	16.8		442.8	0.065
13	4.1		72.9	0.006
14				0.724
15				
16				
17				
18				0.359
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	160	55	215	133
38				
39	237		4,891	
40				

(continued)

TABLE A-9 (continued)

	53	54	55	56
	Coal dryer off-gas	Cooled off-gas	Off-gas recycle to coal dryer	Acetone to recycle tank
1	133.8	133.8	Nil	133.8
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18		133.8		133.8
19	133.8			
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	133	85		85
38				
39		677		677
40	30,018			

(continued)

TABLE A-9 (continued)

	57	59	60	61
	Wash solution to evaporator	Process steam from evaporator	Evaporator bottoms	Acetone stripper feed
1	464.3	192.5	271.7	504.9
2				
3				
4				
5				
6				
7				
8				
9	384.2	192.5	191.6	108.8
10	0.048		0.048	0.005
11	5.7		5.7	0.161
12	65.3		65.3	8.1
13	8.9		8.9	0.755
14				3.2
15				
16				
17				
18				383.7
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	218	290	290	85
38		35	35	15
39	1,556			2,584
40			786	

(continued)

TABLE A-9 (continued)

	62	63	64	65
	Stripped acetone	Stripper bottoms	Sulfur product	Stripper bottoms to process cooler
1	383.7	121.2	3.2	117.9
2				
3				
4				
5				
6				
7				
8				
9		108.8		108.8
10		0.005		0.005
11		0.161		0.161
12		8.1		8.1
13		0.755		0.755
14		3.2	3.2	
15				
16				
17				
18				
19	383.7			
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	174	250	250	250
38	15	15		
39		442	7	435
40				

(continued)

TABLF A-9 (continued)

	66	67	68	69
	Stripper bottoms to surge tank	Stripper bottoms to neutralizer	Slaked lime feed to neutralizer	Pond feed
1	117.9	117.9	98.8	291.8
2				
3				
4				
5				
6				
7				
8				
9	108.8	108.8	79.0	229.2
10	0.005	0.005		0.600
11	0.161	0.161		
12	8.1	8.1		
13	0.755	0.755		
14				
15				
16			19.7	
17				45.9
18				
19				
20				2.6
21				13.3
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	160	160		
38				
39	435	435	316	1,015
40				

(continued)

TABLE A-9 (continued)

	70	71	72	73
	Pond settled solids	Pond return water	Condensed acetone from stripper to recycle tank	Acetone make-up
1	88.5	203.3	383.7	0.359
2				
3				
4				
5				
6				
7				
8				
9	25.9	203.3		
10	0.600			
11				
12				
13				
14				
15				
16				
17	45.9			
18			383.7	0.359
19				
20	2.6			
21	13.3			
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	55	55	85	55
38				
39	202	845	1,942	1.4
40				

(continued)

TABLE A-9 (continued)

	74	75	76	77
	Acetone feed to sulfur removal system	Sulfur to product storage	Cleaned coal to briquetting plant	Cleaned coal to briquetting bypass
1	518.0	3.2	335.0	84.6
2				
3				
4			212.3	53.6
5			0.306	0.077
6				
7			6.8	1.7
8			66.4	16.7
9			48.2	12.1
10				
11			0.0008	0.0002
12			0.052	0.013
13			0.005	0.001
14		3.2	0.578	0.146
15				
16				
17				
18	518.0		0.285	0.074
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	85	250	225	225
38				
39	2,621	7		
40				

(continued)

TABLE A-9 (continued)

	78	79	80	81
	Briquetted coal product	Cleaned coal product to storage	Combined coal product to storage	Makeup water
1	335.0	419.6	697.7	383.1
2				
3				
4	212.3	266.0	448.1	
5	0.306	0.383	0.483	
6				
7	6.8	8.5	9.0	
8	66.4	83.2	86.7	
9	48.2	60.3	152.1	383.1
10				
11	0.0008	0.001	0.008	
12	0.052	0.065	0.083	
13	0.005	0.006	0.012	
14	0.578	0.724	0.724	
15				
16				
17				
18	0.285	0.359	0.359	
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37				55
38				
39				1,291
40				

(continued)

TABLE A-9 (continued)

	82	83	84	85
	Lime to slaker	Water to slaker	Slaked lime to surge tank	Low pressure steam to coal heat
1	14.9	83.8	98.8	6.1
2				
3				
4				
5				
6				
7				
8				
9		83.8	79.0	6.1
10				
11				
12				
13				
14				
15				
16			19.7	
17				
18				
19				
20				
21				
22	14.9			
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	55	55		281
38				35
39		316	316	
40				

(continued)

TABLE A-9 (continued)

	85A	86	87	88
	Total steam to coal heat	Cooling water feed to E-1	Water to cooling tower surge tank	Cooling water feed to E-3
1	36.0	2353.0	2353.0	1133.0
2				
3				
4				
5				
6				
7				
8				
9	36.0	2353.0	2353.C	1133.0
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	219	55	89	55
38	2.3			
39		9,415	9,415	4,533
40				

(continued)

TABLE A-9 (continued)

	89	90	91	92
	Water to cooling tower surge tank	Low pressure steam to E-4	Low pressure condensate from E-4	Cooling water feed to E-5
1	1133.0	28.6	28.6	905.0
2				
3				
4				
5				
6				
7				
8				
9	1133.0	28.6	28.6	905.0
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	93	281	281	55
38		35	35	
39	4,533		115	3,621
40				

(continued)

TABLE A-9 (continued)

	93	94	95	96
	Water to cooling tower surge tank	Low pressure steam to E-6	Low pressure condensate from E-6	Low pressure steam to E-7
1	905.0	60.4	60.4	20.8
2				
3				
4				
5				
6				
7				
8				
9	905.0	60.4	60.4	20.8
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	80	281	281	281
38		35	35	35
39	3,621		242	
40				

(continued)

TABLE A-9 (continued)

	97	100	101	102
	Low pressure condensate from E-7	High pressure steam to evaporator	High pressure condensate from evaporator	Process steam to stripper
1	20.8	254.5	254.5	192.5
2				
3				
4				
5				
6				
7				
8				
9	20.8	254.5	254.5	192.5
10				
11				
12				
13				
14				
15				
16				
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20				
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22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	281	422	422	290
38	35	300	300	35
39	83		939	
40				

(continued)

TABLE A-9 (continued)

	103	104	105	106
	Process steam condensate from stripper	Cooling water feed to E-10	Water to cooling tower surge tank	Cooling water feed to E-11
1	192.5	422.4	1335.4	118.0
2				
3				
4				
5				
6				
7				
8				
9	192.5	422.4	1335.4	118.0
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
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27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	281	55	139	55
38	35			
39	563	1,690	5,343	472
40				

(continued)

TABLE A-9 (continued)

	107	108	109	110
	Water to cooling tower surge tank	High pressure steam to coal dryer	High pressure condensate from dryer	Cooling water feed to E-12
1	118.0	123.3	123.3	801.3
2				
3				
4				
5				
6				
7				
8				
9	118.0	123.3	123.3	801.3
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	142	422	422	55
38		300	300	
39	472		479	3,206
40				

(continued)

TABLE A-9 (continued)

	111	112	113	114
	Water to cooling water surge tank	Low pressure steam to sulfur storage	Low pressure condensate from sulfur storage	Cooling tower feed
1	801.3	0.004	0.004	5732.8
2				
3				
4				
5				
6				
7				
8				
9	801.3	0.004	0.004	5732.8
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	100	281	281	104
38		35	35	
39	3,206		0.016	22,937
40				

(continued)

TABLE A-9 (continued)

	115			
	Cooling tower discharge to river			
1	6645.7			
2				
3				
4				
5				
6				
7				
8				
9	6645.7			
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37	65			
38				
39	26,590			
40				

TABLE A-10. TRW GRAVICHEM COAL DESULFURIZATION PROCESS

EQUIPMENT LIST - BASE CASE (5% S COAL)

Area 1--Raw Material Handling and Preparation

	Item	No.	Description
1.	Conveyor, coal unloading	1	1000 ton/hr, 42-in. belt, 500 ft long, 100-hp motor, 2 fixed trippers, CS
2.	Conveyor, coal stocker	2	1000 ton/hr, 42-in. belt, 968 ft long, 40-hp motor, 1 traveling tripper, CS
3.	Hopper, pile reclaim	20	13-ft x 13-ft top opening, 3-ft-deep pyramid, with 22-in. x 22-in. bottom opening, CS
4.	Feeders, vibrating pan	20	120 ton/hr, 24 in. wide, 42-in. long pan, with 1.5-hp vibrator, CS
5.	Conveyor, coal transfer	2	593 ton/hr, 42-in. belt, 970 ft long, 25-hp motor, CS
6.	Tunnel, conveyor	2	7 ft wide, 6 ft deep, 970 ft long, steel reinforced concrete
7.	Pump, tunnel sump	2	60 gpm, 30-ft head, centrifugal, 1-hp motor, CS
8.	Conveyor, coal transfer	1	593 ton/hr, 42-in. belt, 320 ft long, 5-hp motor, CS
9.	Tunnel, conveyor	1	7 ft wide, 6 ft deep, 320 ft long, steel reinforced concrete
10.	Pump, tunnel sump	1	60 gpm, 30-ft head, centrifugal, 1-hp motor, CS
11.	Conveyor, crusher feed	1	593 ton/hr, 42-in. belt, 565 ft long, 100-hp motor, totally enclosed, CS
12.	Sampler, coal	1	Automatic coal sampler
13.	Bin, coal surge	1	7200 ft^3, 19 ft wide, 19 ft long, 20 ft high, 10-ft-deep pyramid bottom, closed top, CS

(continued)

TABLE A-10 (continued)

	Item	No.	Description
14.	Feeder, weigh belt	1	593 ton/hr, 42-in. belt, 10 ft long, 5-hp motor, CS
15.	Crusher, coal	2	300 ton/hr, ring-type granulator, 150-hp motor, totally enclosed, CS
16.	Pulverizer, coal	2	300 ton/hr, reversible impactor, 400-hp motor, totally enclosed, CS
17.	Elevator, coal	8	148 ton/hr, 70 ft high, 24-in. x 8-in. x 11-3/4-in. continuous buckets, belt drive, 15-hp motor, CS
18.	Conveyor, coal transfer	1	593 ton/hr, 42-in. belt, 140 ft long, 25-hp motor, 4 fixed trippers, totally enclosed, CS
19.	Pump, acid unloading	2	44 gpm, 100-ft head, centrifugal, 5-hp motor, neoprene lined, CS
20.	Tank, acid storage	1	988,000 gal, 58-ft-diameter, 50 ft high, flat bottom, closed top, neoprene lined, CS
21.	Pump, acid feed	2	23 gpm, 100-ft head, centrifugal, 2-hp motor, neoprene lined, CS
22.	Pump, acetone unloading	2	102 gpm, 100-ft head, centrifugal, 5-hp motor, CS
23.	Tank, acetone storage	1	71,500 gal, 23-ft-diameter, 23 ft high, flat bottom, closed top, CS
24.	Pump, acetone feed	2	1-1/2 gpm, 100-ft head, centrifugal, 1/8-hp motor, CS
25.	Hoist, car shaker	1	2,000-lb capacity, 1.5-hp motor
26.	Shaker, car	1	Railroad track side vibrator, 20 hp
27.	Puller, car	1	Railroad, car puller with base, wire rope, 25-hp motor, 5-hp return motor

(continued)

TABLE A-10 (continued)

	Item	No.	Description
28.	Hopper, railcar unloading	1	94 ft^3, 8 ft 4 in. x 8 ft 4 in. top opening, 3-ft-deep pyramid, with 2 ft 4 in. x 2 ft 4 in. bottom opening
29.	Feeder, lime vibrating	1	210 ton/hr, 42 in. wide, 5-ft-long pan, 2.5-hp vibrator, CS
30.	Conveyor, lime unloading	1	210 ton/hr, 24-in. belt, 10 ft long, 2.5-hp motor, CS
31.	Conveyor, lime unloading	1	210 ton/hr, 24-in. belt, 436 ft long, 30-hp motor, totally enclosed, CS
32.	Tunnel, conveyor	1	7 ft wide, 6 ft deep, 70 ft long, steel reinforced concrete
33.	Pump, tunnel sump	1	20 gpm, 20-ft head, centrifugal, 0.5-hp motor, CS
34.	Silo, lime storage	1	407,000 ft^3, 72-ft-diameter, 100 ft high, cone bottom, closed top, CS
35.	Feeder, weigh belt	1	20 ton/hr, 12-in. belt, 10 ft long, 0.5-hp motor, CS
36.	Conveyor, slaker feed	1	20 ton/hr, 12-in. belt, 40 ft long, 0.75-hp motor, CS
37.	Slaker, lime	1	100 ton/hr of 20% slaked slurry product, 20 ft x 43 ft x 9.5 ft high, 2-hp motor, on rake drive, 30-hp mixer
38.	Pump, slaked lime product	2	316 gpm, 100-ft head, centrifugal, 20-hp motor, neoprene lined, CS
39.	Tank, 20% lime feed	1	159,000 gal, 30-ft-diameter, 30 ft side, flat bottom, closed top, neoprene lined, CS
40.	Agitator, 20% lime feed tank	1	15 hp, neoprene coated, CS
41.	Pump, lime feed	2	316 gpm, 100-ft head, centrifugal, 20-hp motor, neoprene lined, CS

(continued)

TABLE A-10 (continued)

Item	No.	Description
42. Conveyor, copperas unloading	1	210 ton/hr, 24-in. belt, 252 ft long, 25-hp motor, totally enclosed, CS
43. Tunnel, conveyor	1	7 ft wide, 6 ft deep, 70 ft long, steel reinforced concrete
44. Pump, tunnel sump	1	20 gpm, 20-ft head, centrifugal, 0.5-hp motor, CS
45. Tank, copperas storage	1	43,000 ft^3, 38-ft-diameter, 38 ft high, cone bottom, closed top, 316 SS
46. Feeder, weigh belt	1	3.5 ton/hr, 18-in. belt, 10 ft long, 0.75-hp motor, CS

Area 2--"Gravichem" Separation

Item	No.	Description
1. Bin, coal feed	4	47,100 ft^3, 35-ft-diameter, 49 ft high, cone bottom, closed top, CS
2. Tank, slurry mix	2	367,200 gal, 25-ft-diameter, 100 ft long, horizontal, operating at 215°F and atmospheric pressure, 316L SS
3. Agitators, slurry mix tank	6	25 hp, 316L SS
4. Drum, knockout	2	10,100 gal, 8-ft-diameter, 27 ft long, dish head ends, 316L SS
5. Pump, cyclone feed	3	2,672 gpm, 125-ft head, centrifugal, 250-hp motor, 316L SS
6. Cooler, coal slurry	13	2,080 ft^2 area, Hastelloy C
7. Cyclone, heavy media	54	10.49 ton/hr solids, 6-in.-diameter heavy medium cyclone, operating at 40 psig
8. Tank, cyclone underflow	2	3,400 gal, 8-ft-diameter, 9 ft high, cone bottom, closed top, neoprene lined, CS

(continued)

TABLE A-10 (continued)

Item	No.	Description
9. Agitator, underflow tank	2	10 hp, neoprene coated, CS
10. Pump, reactor feed	3	1,111 gpm, 100-ft head, centrifugal, 100-hp motor, neoprene lined, CS
11. Feeder, coal weigh	2	296.5 ton/hr, 30-in. belt, 10 ft long, 1.5-hp motor, CS

Area 3--Float Coal Washing

Item	No.	Description
1. Filter, coal	3	62 ton/hr, 12-ft-diameter, 24 ft long, 912 ft^2 area, rotary drum type, 5-hp motor drive, 3-hp agitator, 316L SS
2. Pump, vacuum	6	200-hp system, 316L SS
3. Tank, filtrate	6	750 gal, 4-ft-diameter, 8 ft long, vacuum receiver, 316L SS
4. Pump, filtrate	5	887 gpm, 100-ft head, centrifugal, 60-hp motor, neoprene lined, CS
5. Pump, filtrate	5	248 gpm, 100-ft head, centrifugal, 15-hp motor, neoprene lined, CS
6. Tank, coal wash	1	11,000 gal, 12-ft-diameter, 13 ft high, cone bottom, neoprene lined, CS
7. Agitator, wash tank	1	7.5 hp, neoprene coated, CS
8. Pump, filter feed	2	1,111 gpm, 100-ft head, centrifugal, 80-hp motor, neoprene lined, CS
9. Filter, coal	3	62 ton/hr, 12-ft-diameter, 24 ft long, 912 ft^2 area, rotary drum type, 5-hp motor drive, 3-hp agitator, 316L SS
10. Pump, vacuum	6	200-hp system, 316L SS

(continued)

TABLE A-10 (continued)

	Item	No.	Description
11.	Tank, filtrate	6	750 gal, 4-ft-diameter, 8 ft long, vacuum receiver, 316L SS
12.	Pump, filtrate	10	248 gpm, 100-ft head, centrifugal, 15-hp motor, neoprene lined, CS
13.	Tank, coal wash	1	11,000 gal, 12-ft-diameter, 13 ft high, cone bottom, neoprene lined, CS
14.	Agitator, wash tank	1	7.5 hp, neoprene coated, CS
15.	Pump, filter feed	2	111 gpm, 100-ft head, centrifugal, 80-hp motor, neoprene lined, CS
16.	Filter, coal	3	62 ton/hr, 12-ft-diameter, 24 ft long, 912 ft^2 area, rotary drum type, 5-hp motor drive, 3-hp agitator, 316L SS
17.	Pump, vacuum	6	200-hp system, 316L SS
18.	Tank, filtrate	6	750 gal, 4-ft-diameter, 8 ft long, vacuum receiver, 316L SS
19.	Pump, filtrate	10	248 gpm, 100-ft head, centrifugal, 15-hp motor, neoprene lined, CS
20.	Heater, wash water	1	1,151 ft^2 area, CS
21.	Conveyor, coal product	1	638 ton/hr, 42-in. belt, 1,120 ft long, 75-hp motor, 2 fixed trippers, totally enclosed, CS
22.	Sampler, coal	1	Automatic coal sampler

Area 4--Reactor - Regenerator

	Item	No.	Description
1.	Reactor, leach	3	270,300 gal, 21-ft-diameter, 115 ft long, horizontal, 50 psig operating pressure, 4 Hastelloy C dividers, 85 mill polypropylene liner, 6-in. acid brick liner, 10 agitator openings, Shell is CS
2.	Agitators, reactor	30	200 hp, Hastelloy C

(continued)

TABLE A-10 (continued)

Item	No.	Description
3. Drum, knockout	3	12,900 gal, 9-ft-diameter, 27 ft long, dish head ends, 316L SS
4. Pump, leachate feed	5	1,631 gpm, 100-ft head, centrifugal, 100-hp motor, 316L SS
5. Drum, flash	3	7,500 gal, 8-ft-diameter, 20 ft long, dish head ends, 316L SS
6. Compressor, oxygen	1	2,500 ft^3/min, at 110 psig, centrifugal, 600-hp motor, CS
7. Pump, filtrate feed	5	706 gpm, 100-ft head, centrifugal, 75-hp motor, 316L SS
8. Cooler, reactor slurry	8	1,877 ft^2 area, Hastelloy C
9. Filter, coal	5	72.4 ton/hr, 12-ft-diameter, 24 ft long, 912 ft^2 area, rotary drum type, 5-hp motor drive, 3-hp agitator, 316L SS
10. Pump, vacuum	10	200-hp system, 316L SS
11. Tank, filtrate	10	750 gal, 4-ft-diameter, 8 ft long, vacuum receiver, 316L SS
12. Pump, filtrate	8	328 gpm, 100-ft head, centrifugal, 25-hp motor, neoprene lined, CS
13. Pump, filtrate	8	163 gpm, 100-ft head, centrifugal, 10-hp motor, neoprene lined, CS
14. Heater, wash water	1	1,583 ft^2 area, CS
15. Heater, leachate	6	2,314 ft^2 area, Hastelloy C
16. Regenerator, leachate	1	70,000 gal, 11-ft-diameter, 119 ft long, horizontal, 35 psig operating pressure, 4 Hastelloy C dividers, 85 mill polypropylene liner, 6-in. acid brick liner, 10 agitator openings, Shell is CS

(continued)

TABLE A-10 (continued)

Item	No.	Description
17. Agitators, regenerator	10	100 hp, Hastelloy C
18. Pump, filtrate return	2	2,414 gpm, 100-ft head, centrifugal, 150-hp motor, 316L SS
19. Tank, leachate return	1	49,300 gal, 20-ft-diameter, 21 ft high, flat bottom, closed top, 316L SS
20. Agitator, leachate return tank	1	15 hp, Hastelloy C
21. Pump, leachate feed	5	1,631 gpm, 100-ft head, centrifugal, 100-hp motor, 316L SS

Area 5--Acetone Leaching

Item	No.	Description
1. Tank, acetone mix	5	5,000 gal, 9.5-ft-diameter, 9.5 ft high, cone bottom, closed top, neoprene lined, CS
2. Agitators, acetone mix tank	5	10 hp, neoprene coated, CS
3. Pump, acetone slurry	8	507 gpm, 100-ft head, centrifugal, 30-hp motor, neoprene lined, CS
4. Cooler, acetone slurry	27	1,295 ft^2 area, 316L SS
5. Filter, coal	12	30.2 ton/hr, 24-ft-diameter, 445 ft^2 area, horizontal rotary pan type, 5-hp motor, 316L SS
6. Pump, vacuum	12	150-hp system, 316L SS
7. Tank, filtrate	12	750 gal, 4-ft-diameter, 8 ft long, vacuum receiver, 316L SS
8. Pump, filtrate	18	211 gpm, 100-ft head, centrifugal, 7.5-hp motor, CS

(continued)

TABLE A-10 (continued)

Area 6--Acetone Recovery and Coal Drying

Item	No.	Description
1. Tank, stripper feed	1	7,100 gal, 10-ft-diameter, 12 ft high, cone bottom, closed top, 316L SS
2. Pump, stripper feed	2	2,384 gpm, 250-ft head, centrifugal, 180-hp motor, 316L SS
3. Preheater, stripper	2	3,100 ft^2 area, 316L SS and Hastelloy C
4. Stripper, acetone	1	16-ft-diameter, 90 ft high, 33 valve trays, 45 psig design pressure, 316L SS
5. Reboiler, stripper	2	13,500 ft^2 area, 316L SS and Hastelloy C
6. Condensor, acetone	6	5,500 ft^2 area, 316L SS
7. Drum, reflux	1	25,400 gal, 12-ft-diameter, 30 ft long, horizontal, 45 psig design pressure, 316L SS
8. Pump, reflux	2	1,620 gpm, 325-ft head, centrifugal, 160-hp motor, 316L SS
9. Cooler, acetone	1	1,900 ft^2 area, 316L SS
10. Pump, bottoms	2	442 gpm, 100-ft head, centrifugal, 25-hp motor, 316L SS
11. Drum, bottoms receiver	1	1,500 gal, 6-ft-diameter, 7 ft long, horizontal, operating pressure 15 psig, 316L SS
12. Cooler, bottoms	4	4,000 ft^2 area, 316L SS and Hastelloy C
13. Tank, bottoms surge	1	1,500 gal, 6-ft-diameter, 7 ft high, cone cottom, closed top, neoprene lined, CS
14. Pump, neutralizer feed	2	437 gpm, 100-ft head, centrifugal, 20-hp motor, neoprene lined, CS
15. Tank, sulfur surge	1	25 gal, 1-ft-diameter, 4 ft high, cone bottom, closed top, 316L SS

(continued)

TABLE A-10 (continued)

Item	No.	Description
16. Pump, sulfur	2	7 gpm, 100-ft head, centrifugal, 0.75-hp motor, 316L SS
17. Tank, acetone recycle	1	8,200 gal, 10-ft-diameter, 14 ft high, cone bottom, closed top, CS
18. Pump, acetone recycle	2	2,621 gpm, 100-ft head, centrifugal, 100-hp motor, CS
19. Bin, dryer feed	12	15,700 ft^3, 20-ft-diameter, 50 ft high, cone bottom, closed top, CS
20. Dryer, coal	12	8-ft-diameter, 80 ft long, 8,480 ft^2 area, rotary steam tube type, 60-hp motor, sealed for solvent recovery
21. Condenser, acetone	5	972 ft^2 area, 316L SS
22. Tank, acetone receiver	12	212 gal, 3-ft-diameter, 4 ft high, dish head ends, 316L SS
23. Fan, induced draft	12	3,000 aft^3/min at 85°F, ΔP, 10 in. H_2O, 10-hp motor, CS
24. Conveyor, dryed coal	1	420 ton/hr, 30-in. belt, 280 ft long, 7.5-hp motor, totally enclosed, CS
25. Sampler, coal	1	Automatic coal sampler

Area 7--Leach Solution Concentration

Item	No.	Description
1. Tank, evaporator feed	1	7,600 gal, 10-ft-diameter, 13 ft high, flat bottom, closed top, neoprene lined, CS
2. Pump, evaporator feed	2	2,379 gpm, 100-ft head, centrifugal, 125-hp motor, neoprene lined, CS
3. Preheater, evaporator	4	1,757 ft^2 area, Hastelloy C
4. Evaporator	1	26-ft-diameter, long tube natural circulation type, 42-in.-diameter circulating pipe, 17,000 ft^2 area heating element, all titanium construction

(continued)

TABLE A-10 (continued)

	Item	No.	Description
5.	Pump, leachate return	2	786 gpm, 100-ft head, centrifugal, 40-hp motor, 316L SS

Area 8--Neutralization and Pond Water Handling

	Item	No.	Description
1.	Tank, neutralizer	1	10,200 gal, 12-ft-diameter, 12 ft high, cone bottom, closed top, neoprene lined, CS
2.	Agitator, neutralizer tank	1	5 hp, neoprene coated, CS
3.	Pump, pond feed	2	917 gpm, 300-ft head, centrifugal, 150-hp motor, neoprene lined, CS
4.	Pipeline, pond feed	2	5,280 ft long, 10-in.-diameter, rubber lined, CS
5.	Pump, pond return	2	845 gpm, 300-ft head, centrifugal, 125-hp motor, CS
6.	Pipeline, pond return	1	5,280 ft long, 10-in.-diameter, CS
7.	Tank, recycle water	1	34,500 gal, 14-ft-diameter, 30 ft high, flat bottom, closed top, CS
8.	Pump, wash water	2	744 gpm, 100-ft head, centrifugal, 40-hp motor, CS
9.	Pump, wash water	2	1,010 gpm, 100-ft head, centrifugal, 50-hp motor, CS
10.	Pump, leachate recycle tank feed	2	25 gpm, 100-ft head, centrifugal, 1.5-hp motor, CS
11.	Pump, slaker feed	2	316 gpm, 100-ft head, centrifugal, 15-hp motor, CS
12.	Pump, makeup water	2	1,250 gpm, 100-ft head, centrifugal, 60-hp motor, CS

(continued)

TABLE A-10 (continued)

Area 9--Product Agglomeration and Handling

	Item	No.	Description
1.	Conveyor, coal	1	287 ton/hr, 30-in. belt, 100 ft long, 3-hp motor, totally enclosed, CS
2.	Elevator, coal	2	144 ton/hr, 40 ft high, 24 in. x 8 in. x 11-3/4 in. continuous buckets, belt drive, 15-hp motor, CS
3.	Conveyor, coal	1	287 ton/hr, 30-in. belt, 190 ft long, 40-hp motor, totally enclosed, 12 fixed trippers, CS
4.	Briquetting plants	12	25 ton/hr package briquetting plants, including hot briquetter and all support systems
5.	Conveyor, briquett	1	144 ton/hr, 24-in. belt, 185 ft long, 2-hp motor, totally enclosed, CS
6.	Conveyor, coal bypass	1	73 ton/hr, 18-in. belt, 210 ft long, 1.5-hp motor, totally enclosed, CS
7.	Conveyor, transfer	1	217 ton/hr, 24-in. belt, 180 ft long, 3-hp motor, totally enclosed, CS
8.	Conveyor, stacking	2	638 ton/hr, 42-in. belt, 968 ft long, 30-hp motor, traveling tripper, CS
9.	Hopper, pile reclaim	20	13 ft x 13 ft top opening, 3-ft-deep pyramid with 22 in. x 22 in. bottom opening, CS
10.	Feeders, vibrating pan	20	120 ton/hr, 24 in. wide, 42-in.-long pan, 1.5-hp vibrator, CS
11.	Conveyor, coal transfer	2	1,000 ton/hr, 42-in. belt, 970 ft long, 40-hp motor, CS
12.	Tunnel, conveyor	2	7 ft wide, 6 ft deep, 970 ft long, steel reinforced concrete
13.	Tunnel, conveyor	1	7 ft wide, 6 ft deep, 320 ft long, steel reinforced concrete
14.	Pump, tunnel sump	3	60 gpm, 30-ft head, centrifugal, 1-hp motor, CS

(continued)

TABLE A-10 (continued)

Item	No.	Description
15. Tank, sulfur storage	1	5,200 gal, 9-ft-inside-diameter, 11-ft-inside-height, flat bottom, closed top, totally underground, 10-in.-thick steel reinforced concrete construction
16. Pump, sulfur	2	40 gpm, 100-ft head, centrifugal, 5 hp, 316L SS

Area 10--Utility Water Handling

Item	No.	Description
1. Pump, makeup water	2	1,250 gpm, 100-ft head, centrifugal, 60-hp motor, CS
2. Pump, cooling water	2	9,415 gpm, 100-ft head, centrifugal, 400-hp motor, CS
3. Pump, cooling water	2	4,533 gpm, 100-ft head, centrifugal, 200-hp motor, CS
4. Pump, cooling water	2	3,621 gpm, 100-ft head, centrifugal, 175-hp motor, CS
5. Pump, cooling water	2	1,690 gpm, 245-ft head, centrifugal, 155-hp motor, CS
6. Pump, cooling water	2	472 gpm, 100-ft head, centrifugal, 20-hp motor, CS
7. Pump, cooling water	2	3,206 gpm, 100-ft head, centrifugal, 150-hp motor, CS
8. Tank, cooling tower feed	1	81,200 gal, 24-ft-diameter, 24 ft high, flat bottom, open top, CS
9. Pump, cooling tower feed	6	5,734 gpm, 100-ft head, centrifugal, 250-hp motor, CS
10. Tower, cooling	1	26,590 gpm, mechanical draft, crossflow type, 510 total hp

(continued)

TABLE A-10 (continued)

Item	No.	Description
11. Basin, cooling tower	1	6,000 ft^2 area basin, steel reinforced concrete
12. Pump, cooling tower	2	26,590 gpm, 30-ft head, centrifugal, 350-hp motor, CS

Area 11--Settling Pond

Item	No.	Description
1. Pond	1	468 acres, 21.73 ft deep, with clay lining

TABLE A-11. KENNECOTT COAL DESULFURIZATION PROCESS

MATERIAL BALANCE - BASE CASE

	Stream Number	1	2	3	4	5	6	7
	Description	Coal to ball mills	Water to ball mill	Slurry to surge tank	Slurry to preheater	Slurry to flash-gas scrubber	Slurry to scrubber catch tank	Slurry to reactor preheater
1	Total, tons/hr	680.0	2298.0	2977.9	2977.9	2977.9	3280.9	3280.9
2								
3	Stream components, tons/hr							
4	Coal	623.4		623.4	623.4	623.4	623.4	623.4
5	Pyritic S	21.9		21.9	21.9	21.9	21.9	21.9
6	Sulfate S	0.41						
7	Organic S	10.4		10.4	10.4	10.4	10.4	10.4
8	H_2O	23.8	2298.0	2321.8	2321.8	2321.8	2624.8	2624.8
9	O_2							
10	CO							
11	CO_2							
12	$FeSO_4$							
13	$Fe(OH)_2$							
14	Fe_2O_3							
15	H_2SO_4							
16	O_2 Coal uptake							
17	Sulfate in solution			0.41	0.41	0.41	0.41	0.41
18	O_2 in solution							
19	CaO							
20	$Ca(OH)_2$							
21	$Ca(SO_4)\cdot 2H_2O$							
22	Binder							
23								
24								
25								
26								
27								
28								
29								
30								
31								
32								
33								
34								
35								
36	Temperature, °F	55.0	55.0	65.0	65	150	250	250
37	Pressure, psig				20	15	15	
38	gpm		9194.0	9289.0	9289	9289	10,502	10,502
39								
40								

(continued)

TABLE A-11 (continued)

	8	9	10	11
	Slurry to reactor	O_2 to reactor	Reactor off-gas	Slurry to flash tank
1	3280.9	129.3	71.8	3338.3
2				
3				
4	623.4			597.9
5	21.9			2.6
6				
7	10.4			8.9
8	2624.8		10.6	2604.6
9		129.3	30.6	
10			1.6	
11			29.0	
12				11.4
13				
14				18.3
15				56.2
16				36.7
17	0.41			0.41
18				1.29
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	350		350	350
37	315	315	315	315
38	10,502			10,544
39				
40				

(continued)

TABLE A-11 (continued)

	12	13	14	15
	Flash steam to scrubber	Flash tank slurry outlet	Slurry to preheater	Slurry to thickener
1	304.29	3034.0	3034.0	3034.0
2				
3				
4		597.9	597.9	597.9
5		2.6	2.6	2.6
6				
7		8.9	8.9	8.9
8	303	2301.6	2301.6	2301.6
9				
10				
11				
12		11.4	11.4	11.4
13				
14		18.3	18.3	18.3
15		56.2	56.2	56.2
16		36.7	36.7	36.7
17		0.41	0.41	0.41
18	1.29			
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	250	250	250	166
37	15	15		
38		9332	9332	9332
39				
40				

(continued)

TABLE A-11 (continued)

	16	17	18	19
	Thickener overflow	Slurry feed to filter	Cake to reslurry tank	Slurry feed to filter
1	1135.4	1898.6	1022.2	1898.4
2				
3				
4		597.9	597.9	597.9
5		2.6	2.6	2.6
6				
7		8.9	8.9	8.9
8	1102.9	1198.7	354.4	1230.6
9				
10				
11				
12	5.4	5.94	0.57	0.57
13				
14		18.3	18.3	18.3
15	26.9	29.2	2.8	2.8
16		36.7	36.7	36.7
17	0.20	0.21	0.02	0.02
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	166	166	166	166
37				
38	4472	4860		5004
39				
40				

(continued)

TABLE A-11 (continued)

	20	21	22	23
	Filter solids	Pelletizing bypass	Coal feed to pelletizing	Wash water feed to filter
1	1022.3	197.6	824.2	357.9
2				
3				
4	597.9	115.7	482.1	
5	2.6	0.51	2.1	
6				
7	8.9	1.7	7.2	
8	357.4	69.1	288.2	357.9
9				
10				
11				
12	0.085			
13				
14	18.3	3.5	14.7	
15	0.41		0.33	
16	36.7	7.1	29.6	
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	144	144	144	55
37				
38				1432
39				
40				

(continued)

TABLE A-11 (continued)

	24 H_2O to reslurry tank	25 Wash water to filter	26 Filtrate to neutralizer	27 Filtrate to neutralizer
1	876.2	715.7	1234.1	1591.9
2				
3				
4				
5				
6				
7				
8	876.2	715.7	1231.2	1560.0
9				
10				
11				
12			0.485	5.3
13				
14				
15			2.4	26.4
16				
17			0.015	0.19
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	166	166	144	166
37				
38	3506	2864	4931	6299
39				
40				

(continued)

TABLE A-11 (continued)

	28 Lime to slaker	29 Slaked lime to neutralizer	31 Slurry to pond	31a Pond settled solids
1	36.31	239.8	4201.8	164.0
2				
3				
4				
5				
6				
7				
8		191.9	4083.2	52.2
9				
10				
11				
12				
13			7.08	
14				
15				
16				
17				
18				
19	36.31			
20		47.9		
21			111.5	111.5
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	55			55
37				
38		768	16,337	
39				
40				

(continued)

TABLE A-11 (continued)

	32 Pond water recycle	33 Makeup water to recycle tank	34 Scrubber off-gas	35 Binder solution to pelletizing
1	4031.0	420.1	1.29	21.4
2				
3				
4				
5				
6				
7				
8	4031.0	420.1		10.7
9			1.29	
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				10.7
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	55	55	250	55
37			15	
38	16,128	1681		43
39				
40				

(continued)

TABLE A-11 (continued)

	36 Steam from pellet dryer	37 Pelletized product	38 Clean coal product to storage	39 H_2O to slaker
1	271.1	574.6	772.2	203.2
2				
3				
4		482.1	597.9	
5		2.1	2.6	
6				
7		7.2	8.9	
8	271.1	27.8	96.9	203.2
9				
10				
11				
12		0.07	0.09	
13				
14		14.7	18.3	
15		0.33	0.41	
16		29.6	36.7	
17				
18				
19				
20				
21				
22		10.7	10.7	
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	212	212		55
37				
38				813
39				
40				

(continued)

TABLE A-11 (continued)

	40	41	42	
	Steam to reactor preheater	Steam to water heater	Steam to water heater	
1	355.3	98.4	120.5	
2				
3				
4				
5				
6				
7				
8	355.3	98.4	120.5	
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36	422	422	422	
37	300	300	300	
38				
39				
40				

TABLE A-12. KENNECOTT COAL DESULFURIZATION PROCESS

EQUIPMENT LIST - BASE CASE (3% S COAL)

Area 1--Raw Material Handling and Preparation

Item	No.	Description
1. Conveyor, coal unloading transfer	1	1,000 tons/hr, 42-in. belt, 500 ft long, 100-hp motor, with 2 fixed trippers, CS
2. Conveyor, stacker	2	1,000 tons/hr, 42-in. belt, 968 ft long, 40-hp motor, 1 traveling tripper, CS
3. Hoppers, pile reclaim	20	13-ft x 13-ft top opening, 3-ft-deep pyramid, 22-in. x 22-in. bottom opening, CS
4. Feeders, vibrating pan	20	120 tons/hr, 24 in. wide, 42-in.-long pan, with 1-1/2-hp vibrator, CS
5. Tunnels, reclaim	2	7 ft wide, 6 ft deep, 970 ft long, steel reinforced concrete
6. Conveyor, coal transfer	2	680 tons/hr, 42-in. belt, 970 ft long, 25-hp motor, CS
7. Pump, tunnel sump	3	60 gpm, 30-ft head, centrifugal, 1-hp motor, CS
8. Tunnel, transfer	1	7 ft wide, 6 ft deep, 320 ft long, steel reinforced concrete
9. Conveyor, coal transfer	1	680 tons/hr, 42-in. belt, 320 ft long, 10-hp motor, CS
10. Conveyor, crusher feed	1	680 tons/hr, 42-in. belt, 800 ft long, 200-hp motor, totally enclosed, 1 fixed tripper, CS
11. Sampler, coal	1	Automatic coal sampler
12. Bin, coal surge	1	227,000 ft^3, 61 ft wide, 61 ft long, 61 ft high, 31-ft-deep pyramid bottom, closed top, CS
13. Feeder, weigh belt	1	680 tons/hr, 42 in. wide, 10 ft long, 5-hp motor, CS

(continued)

TABLE A-12 (continued)

Item	No.	Description
14. Crusher, coal	2	340 tons/hr, to crush from 3-in.-size coal to 3/4-in. size, 200-hp motor, totally enclosed
15. Bin, coal surge	2	110,600 ft^3, 48 ft wide, 48 ft long, 48 ft high, 24-ft-deep pyramid bottom, closed top, CS
16. Feeder, weigh belt	2	340 tons/hr, 30 in. wide, 10 ft long, 2.5-hp motor, CS
17. Ball mill, coal	2	340 tons/hr, 16-ft diameter, 27 ft long, 4,500-hp motor, wet grind ball mill, to grind coal from 3/4-in. size to 80% minus 100 mesh, 23% solids slurry
18. Tank, product surge	2	14,000 gal, 13-ft diameter, 14 ft high, cone bottom, closed top, neoprene lined, CS
19. Agitator, surge tank	2	5 hp, neoprene coated, CS
20. Pump, cyclone feed	4	4,644 gpm, 100-ft head, centrifugal, 250-hp motor, neoprene lined, CS
21. Cyclone, oversize coal	8	1,161 gpm, 18-in. diameter, heavy duty cyclone, 15-psig operating pressure, high density gum rubber-lined, fiberglass reinforced polyester
22. Tank, cyclone overflow	1	28,900 gal, 17-ft diameter, 17 ft high, cone bottom, closed top, neoprene lined, CS
23. Agitator, overflow tank	1	10 hp, neoprene coated, CS
24. Pump, scrubber feed	2	10,502 gpm, 50-ft head, centrifugal, 300-hp motor, 316L SS
25. Pump, binder unloading	2	100 gpm, 50-ft head, centrifugal, 5-hp motor, CS

(continued)

TABLE A-12 (continued)

Item	No.	Description
26. Tank, binder storage	1	1,880,200 gal, 80-ft diameter, 50 ft high, cone bottom, closed top, CS
27. Pump, binder feed	2	43 gpm, 100-ft head, centrifugal, 5-hp motor, CS
28. Hoist, car shaker	1	2,000-lb capacity with 1.5-hp motor
29. Shaker, car	1	20 hp, railroad, trackside vibrator
30. Puller, car	1	Railroad car puller with base, wire rope, 25-hp motor, 5-hp return motor
31. Hopper, lime unloading	1	94 ft^3, 8-ft 4-in. x 8-ft 4-in. top opening, 3-ft-deep pyramid, with 2-ft 4-in. x 2-ft 4-in. bottom opening, CS
32. Feeder, lime vibrating	1	210 tons/hr, 42 in. wide, 5-ft-long pan, 2.5-hp vibrator, CS
33. Conveyor, lime unloading	1	210 tons/hr, 24-in. belt, 10 ft long, 2.5-hp motor, CS
34. Conveyor, lime unloading	1	210 tons/hr, 24-in. belt, 436 ft long, 30-hp motor, totally enclosed, CS
35. Tunnel, conveyor belt	1	7 ft wide, 6 ft high, 70 ft long, steel reinforced concrete
36. Pump, tunnel sump	1	20 gpm, 20-ft head, centrifugal sump type, 1/2-hp motor, CS
37. Silo, lime storage	2	477,800 ft^3, 78-ft diameter, 100 ft high, cone bottom, closed top, CS
38. Feeder, weigh belt	2	37 tons/hr, 18-in. belt, 10 ft long, 1/2-hp motor, CS
39. Conveyor, slaker feed	1	37 tons/hr, 18-in. belt, 40 ft long, 1/2-hp motor, CS

(continued)

TABLE A-12 (continued)

Item	No.	Description
40. Slaker, lime	1	239.8 tons/hr of 20% slaked slurry product, 20 ft x 43 ft x 9.5 ft high, 2-hp rake drive motor, 30-hp mixer
41. Pump, slaker product	2	768 gpm, 100-ft head, centrifugal, 40-hp motor, neoprene lined, CS
42. Tank, 20% lime feed	1	370,900 gal, 39-ft diameter, 41.5 ft high, flat bottom, closed top, neoprene lined, CS
43. Agitator, 20% lime feed tank	1	75 hp, neoprene coated, CS
44. Pump, 20% lime feed	2	768 gpm, 100-ft head, centrifugal, 40-hp motor, neoprene lined, CS

Area 2--Reactor Area

Item	No.	Description
1. Exchanger, feed/effluent heat	6	5,000 ft^2 area, Carpenter 20 Cb_3
2. Scrubber, flash gas	3	15-ft diameter, 60 ft high, spray tower with 11,000 gal, 15-ft diameter, 8 ft high, cone bottom, surge tank, 15-psig operating pressure, 316L SS
3. Agitator, scrubber	3	3.5 hp, 316L SS
4. Pump, reactor feed	5	3,500 gpm, 730-ft head, centrifugal, 1,500-hp motor, 316L SS
5. Preheater, reactor	5	4,200 ft^2 area, Hastelloy C
6. Reactor, leach	30	28,500 gal, 9-ft diameter, 84 ft long, horizontal, 330-psia operating pressure, 5 Hastelloy C dividers, 85 mill polypropylene liner, 8-in. acid brick liner, 6 agitator openings, shell is CS (3 trains of 10 each)
7. Agitators, reactor	180	75 hp, Hastelloy C

(continued)

TABLE A-12 (continued)

Item	No.	Description
8. Tank, flash	3	11,000 gal, 12-ft diameter, 13 ft high, cone bottom, closed top, 15-psig operating pressure, 250°F, Hastelloy C
9. Pump, thickener feed	5	3,110 gpm, 100-ft head, centrifugal, 200-hp motor, 316L SS

Area 3--Coal Filtration Area

Item	No.	Description
1. Thickener, coal	9	13 ft wide, 22 ft long, 21 ft high, inclined plate gravity settler-thickener with increased volume sludge compartment, 1-hp motor, picket-fence rake
2. Pump, thickener underflow	14	540 gpm, 100-ft head, centrifugal, 40-hp motor, neoprene lined, CS
3. Tank, thickener overflow	3	4,759 gal, 9-ft diameter, 10 ft high, flat bottom, neoprene lined, CS
4. Pump, neutralizer feed	5	1,491 gpm, 100-ft head, centrifugal, 75-hp motor, neoprene lined, CS
5. Heater, wash water	1	985 ft^2 area, CS
6. Filter, coal	24	27.75 tons/hr, 12-ft diameter, 24 ft long, 912 ft^2 area, rotary drum type, 5-hp motor drive, 3-hp agitator, 316L SS
7. Pump, vacuum	24	200-hp system, 316L SS
8. Tank, filtrate	24	750 gal, 4-ft diameter, 8 ft long, vacuum receiver, 316L SS
9. Pump, filtrate	36	400 gpm, 100-ft head, centrifugal, 20-hp motor, neoprene lined, CS
10. Heater, wash water	1	1,810 ft^2 area, CS

(continued)

TABLE A-12 (continued)

Item	No.	Description
11. Tank, coal wash	3	17,300 gal, 14.5-ft diameter, 14 ft high, cone bottom, closed top, neoprene lined, CS
12. Agitator, coal wash tank	3	10 hp, neoprene coated, CS
13. Pump, filter feed	14	556 gpm, 100-ft head, centrifugal, 35-hp motor, neoprene lined, CS
14. Filter, coal	24	74 tons/hr, 12-ft diameter, 24 ft long, 912 ft^2 area, rotary drum type, 5-hp motor drive, 3-hp agitator, 316L SS
15. Pump, vacuum	24	200-hp system, 316L SS
16. Tank, filtrate	24	750 gal, 4-ft diameter, 8 ft long, vacuum receiver, 316L SS
17. Pump, filtrate	36	212 gpm, 100-ft head, centrifugal, 10-hp motor, neoprene lined, CS

Area 4--Product Agglomeration and Handling

Item	No.	Description
1. Conveyor, filtered coal	1	1,023 tons/hr, 42-in. belt, 100 ft long, 10-hp motor, CS
2. Conveyor, coal storage feed	1	773 tons/hr, 42-in. belt, 1,500 ft long, 100-hp motor, 2 fixed trippers, totally enclosed, CS
3. Conveyor, coal bleed	1	825 tons/hr, 42-in. belt, 100 ft long, 10-hp motor, totally enclosed, CS
4. Elevator, coal	5	165 tons/hr, 50 ft high, 24-in. x 8-in. x 11-3/4-in. continuous buckets, belt drive, 15-hp motor, CS
5. Conveyor, pelletizing feed	1	825 tons/hr, 42-in. belt, 510 ft long, 200-hp motor, 33 fixed trippers, totally enclosed, CS

(continued)

TABLE A-12 (continued)

Item	No.	Description
6. Pelletizing plants	33	25 ton/hr pelletizing plant, including 23-ft diameter pan pelletizer, dryers, and all support systems
7. Conveyor, pellet product	1	575 tons/hr, 36-in. belt, 510 ft long, 15-hp motor, totally enclosed CS
8. Conveyor, pellet product	1	575 tons/hr, 30-in. belt, 100 ft long, 5-hp motor, totally enclosed, CS
9. Conveyor, stocking	2	773 tons/hr, 42-in. belt, 968 ft long, 40-hp motor, traveling tripper, CS
10. Hopper, pile reclaim	20	13-ft x 13-ft top opening, 3-ft-deep pyramid with 22-in. x 22-in. bottom opening, CS
11. Feeders, vibrating pan	20	120 tons/hr, 24 in. wide, 42-in.-long pan, 1.5-hp vibrator, CS
12. Conveyor, coal transfer	2	1,000 tons/hr, 42-in. belt, 970 ft long, 40-hp motor, CS
13. Tunnel, conveyor	2	7 ft wide, 6 ft deep, 970 ft long, steel reinforced concrete
14. Tunnel, conveyor	1	7 ft wide, 6 ft deep, 320 ft long, steel reinforced concrete
15. Pump, tunnel sump	3	60 gpm, 30-ft head, centrifugal, 1-hp motor, CS

Area 5--Neutralization and Water Handling

Item	No.	Description
1. Tank, neutralizer	1	169,700 gal, 38-ft diameter, 20 ft high, cone bottom, closed top, neoprene lined, CS

(continued)

TABLE A-12 (continued)

Item	No.	Description
2. Agitator, neutralizer tank	1	15 hp, neoprene coated, CS
3. Pump, pond feed	3	8,169 gpm, 300-ft head, centrifugal, 1,250-hp motor, neoprene lined, CS
4. Pipeline, pond feed	2	36-in. diameter, 5,280 ft long, rubber-lined, CS
5. Pump, pond return	3	8,064 gpm, 300-ft head, centrifugal, 1,250-hp motor, CS
6. Pipeline, pond return	1	36-in. diameter, 5,280 ft long, CS
7. Tank, recycle water	1	8,530,600 gal, 143-ft diameter, 71 ft high, flat bottom, CS
8. Pump, water feed	2	9,194 gpm, 100-ft head, centrifugal, 400-hp motor, CS
9. Pump, water feed	2	1,432 gpm, 100-ft head, centrifugal, 60-hp motor, CS
10. Pump, water feed	2	3,506 gpm, 100-ft head, centrifugal, 150-hp motor, CS
11. Pump, water feed	2	2,864 gpm, 100-ft head, centrifugal, 125-hp motor, CS
12. Pump, water feed	2	813 gpm, 100-ft head, centrifugal, 40-hp motor, CS
13. Pump, makeup water	2	1,681 gpm, 100-ft head, centrifugal, 75-hp motor, CS

Area 6--Settling Pond

Item	No.	Description
1. Pond	1	801 acres, 24.69 ft deep with clay lining

TABLE A-13. COMBINATION PCC-KVB PROCESS

MATERIAL BALANCE FOR 3.5% S COAL

	Stream No.	1	2	3
	Description	Raw coal feed to sizing	2 in.x 3/8 in. coal to coarse coal cleaning	Product from coarse coal cleaning
1	Total stream, tons/hr	840.0	310.5	276.7
2				
3	Stream components, tons/hr			
4	Coal, bone dry	680.1	304.6	265.3
5	Pyritic S	18.3	6.8	3.6
6	Sulfate S	0.4	0.15	0.13
7	Organic S	10.1	3.7	3.3
8	Ash	115.1	42.6	22.4
9	Water	16.0	5.9	11.4
10	NO_2			
11	O_2			
12	SO_2			
13	$FeSO_4$, in coal			
14	$FeSO_4$, in solution			
15	$Fe_2(SO_4)_3$			
16	$Fe(OH)_3$			
17	Sulfate S, in solution			
18	Na_2SO_3			
19	$NaHSO_3$			
20	Na_2SO_4			
21	$Ca(OH)_2$			
22	$CaSO_3$			
23	$CaSO_4$			
24	$CaSO_4 \cdot 2H_2O$			
25	$Na_3Fe_3(SO_4)_2(OH)_6$			
26	CaO			
27	NaOH			
28	Binder			
29	Natural gas			
30	Organic sulfate			
31				
32				
33				
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(continued)

TABLE A-13 (continued)

	4	5	6	7
	Refuse from coarse coal cleaning	3/8 in.x 28 m coal to intermediate coal cleaning	Product from intermediate coal cleaning	Refuse from intermediate coal cleaning
1	40.9	460.4	416.0	69.9
2				
3				
4	39.3	451.7	386.7	65.0
5	3.2	10.0	4.8	5.2
6	0.02	0.23	0.20	0.03
7	0.40	5.6	4.7	0.90
8	20.2	63.3	30.2	33.1
9	1.6	8.7	29.3	4.9
10				
11				
12				
13				
14				
15				
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(continued)

TABLE A-13 (continued)

	8	9	10	11
	28 m x 0 coal to fine coal cleaning	Product from fine coal cleaning	Refuse from fine coal cleaning	Combined refuse to disposal
1	69.1	79.4	12.7	123.5
2				
3				
4	67.7	58.4	9.3	113.6
5	1.4	0.62	0.78	9.[illegible]
6	0.04	0.03	0.01	0.05
7	0.84	0.76	0.08	1.3
8	9.2	4.2	5.0	58.3
9	1.4	21.0	3.4	9.9
10				
11				
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13				
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15				
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(continued)

TABLE A-13 (continued)

	12	13	14A	14B
	Combined physical product to chemical cleaning	Coal to interim storage	Direct coal feed to chemical cleaning (5 days	Feed from interim storage to chemical cleaning (2 days)
1	772.1	220.6	551.5	551.5
2				
3				
4	710.4	181.5	453.9	453.9
5	9.0	2.5	6.4	6.4
6	0.3	0.10	0.25	0.25
7	8.7	2.5	6.2	6.2
8	56.8	16.2	40.5	40.5
9	61.7	17.6	44.0	44.0
10				
11				
12				
13				
14				
15				
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(continued)

TABLE A-13 (continued)

	15	16	17	18
	Pulverized coal to reactor	O_2 makeup	NO_2 makeup	Coarse coal (1/4 in.x 28 m) to coarse coal leaching
1	551.5	11.3	0.119	355.9
2				
3				
4	453.9			293.6
5	6.4			0.08
6	0.25			0.16
7	6.2			2.8
8	40.5			21.1
9	44.0			25.9
10			0.119	
11		11.3		
12				
13				9.6
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				2.4
31				
32				
33				
34				
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37				
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39				
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(continued)

TABLE A-13 (continued)

	19	20	21	22
	Reactor off-gas and fine coal to particulate scrubber	Fine coal to fine coal leaching	Scrubber solution bleed to neutralizer	Off-gas to SO_2 scrubber
1	200.5	188.8	5.7	6.0
2				
3				
4	160.2	160.2		
5	0.05	0.05		
6	0.09	-		
7	1.5	1.5		
8	11.5	11.5		
9	14.1	14.1		
10				
11				
12	6.3		0.32	6.0
13	5.2			
14			5.2	
15				
16				
17			0.09	
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30	1.3	1.3		
31				
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(continued)

TABLE A-13 (continued)

	23	24	25	26
	10% slaked lime feed	20% NaOH makeup	Scrubber solution bleed to the neutralizer	50% NaOH feed to coarse coal leaching
1	69.4	6.3	37.8	17.0
2				
3				
4				
5				
6				
7				
8				
9	62.4	5.0	24.5	8.5
10				
11				
12				
13				
14				
15				
16				
17				
18			1.9	
19				
20				
21	6.9			
22			11.2	
23				
24				
25				
26				
27		1.2		8.5
28				
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(continued)

TABLE A-13 (continued)

	27	28	29	30
	Coarse coal product	Coarse coal bleed to pelletizing	Coarse coal bypass to storage	Coarse coal leach solution to neutralizer
1	343.6	51.5	292.1	18.5
2				
3				
4	293.6	44.0	249.6	
5	0.08	0.012	0.068	
6	0			
7	2.8	0.4	2.4	
8	21.1	3.1	17.9	
9	25.9	3.8	22.0	
10				
11				
12				
13				
14				
15				
16				3.4
17				
18				
19				
20				15.1
21				
22				
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(continued)

TABLE A-13 (continued)

	31	32	33	34
	50% NaOH feed to fine coal leaching	Fine coal product	Fine coal leach solution to neutralizer	Binder feed to pelletizing
1	3.2	189.1	2.9	9.7
2				
3				
4		160.2		
5		0.05		
6		0		
7		1.5		
8		11.5		
9	1.6	15.7		4.8
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20			2.9	
21				
22				
23				
24				
25				
26				
27	1.6			
28				4.8
29				
30				
31				
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(continued)

TABLE A-13 (continued)

	35	36	37	38
	Pelletizing product	Combined clean coal product to storage	20% lime feed to neutralizer	50% NaOH feed to neutralizer
1	237.4	529.5	49.0	0
2				
3				
4	204.2	453.9		
5	0.062	0.13		
6				
7	1.9	4.3		
8	14.7	32.6		
9	11.4	33.5	35.2	0
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21			9.8	
22				
23				
24				
25				
26				
27				0
28	4.8	4.8		
29				
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(continued)

TABLE A-13 (continued)

	39	40	41	42
	Neutralized slurry to settling pond	Pond water return	HP steam to recirculated gas preheater	Steam to coarse coal water heater
1	111.2	37.7	160.9	81.3
2				
3				
4				
5				
6				
7				
8				
9	59.8	37.7	160.9	81.3
10				
11				
12				
13				
14				
15	1.5			
16	3.4			
17				
18	2.6			
19				
20	0.084			
21				
22				
23				
24	38.9			
25	4.7			
26				
27				
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(continued)

TABLE A-13 (continued)

	43	44		
	Steam to fine coal water heater	O_2 to neutralization area		
1	179.4	1.5		
2				
3				
4				
5				
6				
7				
8				
9	179.4			
10				
11		1.5		
12				
13				
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TABLE A-14. COMBINATION PCC-KVB PROCESS

EQUIPMENT LIST - BASE CASE (5% S COAL)

Area 1--Coal Receiving and Storage

	Item	No.	Description
1.	Unloading conveyors for conveying 1,600 tons/hr, 3 in. x 0 raw coal from unloading station to stockpiles	2	Inclined conveyor, 500 ft long, with 1 fixed tripper, 48 in. wide belt, carbon steel, with tramp-iron magnet, 125 hp
2.	Stacking conveyors for distributing coal along the tops of 2 parallel and adjacent wedge-shaped open piles, each of 175,000 tons	2	Elevated horizontal conveyor, 1,000 ft long with 1 traveling tripper, 48 in. wide belt, telescoping chute, carbon steel, 40 hp
3.	Hoppers for reclaiming 807 tons/hr of 3 in. x 0 raw coal from stockpiles	20	Reclaiming hopper with 14 ft x 14 ft top opening, 3-1/2 ft deep pyramid, and 24 in. x 24 in. bottom opening, carbon steel
4.	Pan feeders for withdrawing 807 tons/hr of 3 in. x 0 raw coal from reclaiming hoppers	20	Vibratory pan feeder with 26 in. wide x 48 in. long pan, carbon steel, 1.5 hp vibrator
5.	Collecting conveyors for 807 tons/hr of 3 in. x 0 raw coal from pan feeders	2	Horizontal conveyor, 1,000 ft long with 36 in. wide belt, carbon steel, 35 hp
6.	Tunnels for collecting conveyors	2	Steel-reinforced concrete tunnel 8 ft wide x 6 ft deep x 1,000 ft long
7.	Tunnel sump pump	3	Centrifugal pump, 60 gpm, 30 ft head, carbon steel, 1 hp
8.	Transfer conveyor	1	Horizontal conveyor, 320 ft long with 36 in. wide belt, carbon steel, 10 hp
9.	Tunnel for transfer conveyor	1	Steel-reinforced concrete tunnel, 7 ft wide x 6 ft deep x 320 ft long
10.	Tunnel sump pump	2	Centrifugal pump, 60 gpm, 30 ft head, carbon steel, 1 hp

(continued)

TABLE A-14 (continued)

Item	No.	Description
11. Delivery conveyor for 807 tons/hr of 3 in. x 0 raw coal to raw coal sizing area	1	Inclined conveyor, enclosed 600 ft long, 36 in. wide belt, with belt scale, carbon steel, 75 hp
12. Automatic sampling of coal from stockpile to raw coal sizing area	1	Automatic sampler of plate or similar type conforming with ASTM sampling requirements, primary sampling from 403 tons/hr of 3 in. x 0 coal from delivery conveyors
13. Bulldozer for servicing raw coal storage piles	1	Diesel bulldozer, 100 hp

Area 2--Raw Coal Sizing

Item	No.	Description
1. Raw coal screens for sizing 807 tons/hr of 3 in. x 0 coal to 95 tons/hr of 3 in. x 1-1/4 in., 293 tons/hr of 1-1/4 in. x 3/8 in., and 419 tons/hr of 3/8 in. x 0	4	Double-deck horizontal vibrating screen, 6 ft wide x 16 ft long, low-noise suspension, standard positioning of water sprays for both decks, stainless steel flanged plates for screening at 1-1/4 in. and 3/8 in., carbon steel body, 15 hp
2. Crusher for reducing 95 tons/hr of 3 in. x 1-1/4 in. coal to 2 in. x 0	1	Single roll crusher with 24 in. x 24 in. roll and stationary breaker plate, materials of construction suited to secondary crushing of medium-hard bituminous coal, 25 hp
3. Prewet screen for sizing, 95 tons/hr of crushed coal at 3/8 in.	1	Horizontal vibrating screen, 4 ft wide x 16 ft long, low-noise suspension, standard positioning of water sprays, stainless steel plate for screening at 3/8 in., carbon steel body, 10 hp

(continued)

TABLE A-14 (continued)

Item	No.	Description
4. Sieve bends for partial dewatering and screening of 66 tons/hr of 28 mesh x 0 coal from 508 tons/hr of 3/8 in. x 0 coal	6	Reversible sieve bend, 7 ft wide, with deck of 1/8 in. Bixby-Zimmer Iso-Rod spaced for 1.2 mm opening, including feed box distributor, carbon steel body, 0 hp
5. Fines screens for finish screening of 66 tons/hr of 28 mesh x 0 coal from 508 tons/hr of 3/8 in. x 0 coal	3	Horizontal vibrating screen, 8 ft wide x 16 ft long, deck of 3/32 in. Bixby-Zimmer, Iso-Rod spaced for sizing at 28 mesh, low-noise suspension, standard positioning of water sprays, carbon steel body, 20 hp

Area 3--Coarse Coal Cleaning

Item	No.	Description
1. Dense medium vessels for processing 298 tons/hr of 2 in. x 3/8 in. coal, using magnetite medium at nominal specific gravity of 1.55 for production of 253 tons/hr of float	2	Trough-type vessel, 7 ft wide, with single chain and flight conveyor for float and sink removals at opposite ends of vessel, float and sink inclines constructed from steel wedge wire for drainage of medium from float and sink products to bath, controlled level of bath, controlled distribution of medium recirculated to bath, carbon steel frame and tank, high carbon steel wear bars on conveyor, 20 hp
2. Rinse screens for 253 tons/hr of clean coal (float) at 2 in. x 3/8 in. from dense medium vessel	2	Horizontal vibrating screen, 6 ft wide x 16 ft long, low-noise suspension, standard positioning of water sprays, carbon steel frame, deck of 1/8 inch Bixby-Zimmer Iso-Rod spaced for 1 mm opening, 15 hp

(continued)

TABLE A-14 (continued)

Item	No.	Description
3. Rinse screens for 45 tons/hr of refuse (sink) from dense medium vessel	1	Horizontal vibrating screen, 4 ft wide x 16 ft long, low-noise suspension, standard positioning of water sprays, carbon steel frame, deck of 1/8 in. Bixby-Zimmer Iso-Rod spaced for 1 mm opening, 10 hp
4. Centrifuge for dewatering 253 tons/hr of 2 in. x 3/8 in. clean coal from rinse screens	2	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone-shaped basket of stainless steel screen, individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body, 60 hp total

Area 4--Intermediate Coal Cleaning

Item	No.	Description
1. Dense medium cyclone feed sump for makeup of coal slurry comprising 442 tons/hr coal at 3/8 in. x 28 mesh and 2,290 tons/hr magnetite medium, nominal specific gravity of magnetite medium 1.55	2	Cylindrical tank, 14 ft dia x 2 ft high, with 60° cone bottom and closed top, 7,000 gal, ground-level installation, carbon steel
2. Pumps for feeding coal slurry to dense medium cyclones	3	Centrifugal pump, 3,630 gpm, 70 ft total head, 200 hp
3. Dense medium cyclones for separation of 3/8 in. x 28 mesh coal at specific gravity 1.55	6	Dense medium cyclone, 24 in. dia with tangential entry of feed and exit of clean coal tops, cone angle about 20°, hard nickel or similarly abrasion-resistant iron

(continued)

TABLE A-14 (continued)

Item	No.	Description
4. Sieve bends for partial drainage of medium from 370 tons/hr of clean coal tops from dense medium cyclones	6	Reversible sieve bend, 7 ft wide, with deck of 3/32 in. Bixby-Zimmer Iso-Rod spaced for 3/4 mm opening, including feed box distributor, 0 hp
5. Drain and rinse screens for 370 tons/hr clean coal tops at 3/8 in. x 28 mesh	6	Horizontal vibrating screen, 8 ft wide x 16 ft long, standard positioning of water sprays in rinse section, 2-compartment pan for separate collections of medium and rinse water, low-noise suspension, deck of 3/32 in. Bixby-Zimmer Iso-Rod spaced for 1/2 mm opening, carbon steel frame, 20 hp
6. Centrifuges for dewatering 370 tons/hr of 3/8 in. x 28 mesh clean coal from drain and rinse screens	3	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone shaped basket of stainless steel screen, individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body, 85 hp total
7. Sieve bends for partial drainage of medium from 72 tons/hr of 3/8 in. x 28 mesh refuse from dense medium cyclones	2	Reversible sieve bend, 4 ft wide, with deck of 3/32 in. Bixby-Zimmer Iso-Rod spaced for 3/4 mm opening, including feed box distributor, 0 hp
8. Drain and rinse screens for 72 tons/hr of 3/8 in. x 28 mesh refuse	2	Horizontal vibrating screen, 5 ft wide x 16 ft long, standard positioning of water sprays in rinse section, 2-compartment pan for separate collections of medium and rinse water, low-noise suspension, deck of 3/32 in. Bixby-Zimmer Iso-Rod spaced for 1/2 mm opening, carbon steel frame, 12 hp

(continued)

TABLE A-14 (continued)

Item	No.	Description
9. Centrifuge for dewatering 72 tons/hr of 3/8 in. x 28 mesh refuse from drain and rinse screens	1	Vibrating basket centrifuge, horizontal or vertical axis of basket, cone shaped basket of stainless steel screen, individual motors and drives for basket rotation, for vibration along the axis of the basket, and if so designed, for oil pumping, carbon steel body, 60 hp total
10. Dense medium recovery system for dilute medium from rinse screens in coarse and intermediate cleaning areas	4	Double-drum magnetite recovery unit with permanent magnets in drums, 30 in. dia x 10 ft long drum, 2 drums in series/unit, complete with dilute medium sump, magnetite scraper, etc., installed at elevation above dense medium separators, carbon steel, 10 hp/unit

Area 5--Fine Coal Cleaning

Item	No.	Description
1. Froth flotation feed sump for makeup of coal slurry at 10% solids using 66 tons/hr of 28 mesh x 0 coal	1	Cylindrical tank, 12-1/2 ft dia x 2 ft high with 60^{o} cone bottom and closed top, 5,500 gal, ground-level installation, carbon steel
2. Pump for feeding coal slurry to froth flotation cells	2	Centrifugal pump, 2,700 gpm, 60 ft total head, 75 hp
3. Froth flotation cells for treatment of 66 tons/hr of 28 mesh x 0 coal	1	Bank of 4 froth flotation cells with 300 ft^3/cell, provisions for agitation, aeration, and skimming of froth from cell, each bank arranged with 1 feed box and 1 tailings box, provisions for reagent storage and reagent feeding, carbon steel, 130 hp/bank

(continued)

TABLE A-14 (continued)

Item	No.	Description
4. Disk filter for filtration of 56 tons/hr clean coal from froth flotation	1	Continuous rotary vacuum disk filter, 12 ft, 6 in. dia x 11 disk, 55 stainless steel wire cloth, complete with vacuum pumps and receiver, moisture trap, filtrate pump, and blower, 580 hp
5. Thickener receiving 2,360 gpm of refuse slurry (tailings) from froth flotation and filtrate from refuse filter	1	Single compartment bridge-supported thickener with 80 ft dia reinforced concrete tank, system includes drive unit and lifting device, rake mechanism, feed well, overflow arrangement underflow arrangement, and instrumentation, rotation drive 5 hp, lifting drive, 1 hp
6. Disk filter for filtration of 11 tons/hr refuse (underflow) from thickener	1	Continuous rotary vacuum disk filter, 12 ft, 6 in. dia x 6 disk, stainless steel wire cloth, complete with vacuum pump and receiver, moisture trap, filtrate pump, and blower, 200 hp
7. Pump for returning 2,280 gpm of clarified water	3	Centrifugal pump, 1,140 gpm, 150 ft total head, 75 hp

Area 6--Refuse Disposal

Item	No.	Description
1. Collecting conveyor for 128 tons/hr of 2 in. x 0 refuse	1	Horizontal and inclined belt conveyor, 400 ft long with 24 in. wide belt, carbon steel, 15 hp
2. Refuse bin for truck loading	1	Storage bin, 16 ft wide x 26 ft long x 18 ft high on vertical sides, 13 ft deep pyramidal bottom with fast opening slides for truck loading, 3.5 hp

(continued)

TABLE A-14 (continued)

Item	No.	Description
3. Trucks for transporting 128 tons/hr of 2 in. x 0 refuse 1 mile from coal cleaning plant to refuse disposal site	2	Off-highway diesel-electric dump truck, 100 ton payload, 100 yd^3 capacity, dump body for 2 in. x 0 moist, sluggish, abrasive refuse
4. Refuse disposal site for 30-yr operation	1	"Dry" storage site with 26,000 acre-ft capacity for layered refuse and earth
5. Bulldozer for spreading refuse and earth in layers at disposal site	1	Diesel bulldozer, 100 hp

Area 7--Interim Coal Storage

Item	No.	Description
1. Collecting conveyor for 679 tons/hr of 2 in. x 0 cleaned coal	1	Horizontal conveyor, 300 ft long with 36 in. wide belt, carbon steel, 20 hp
2. Conveyor, storage bypass	1	552 tons/hr, 42 in. belt, 650 ft long, 20 hp motor, carbon steel
3. Conveyor, coal silo feed	1	221 tons/hr, 24 in. belt, 880 ft long, 30 hp motor, 4 fixed trippers, carbon steel
4. Silo, coal storage	4	264,720 ft^3, 70 ft dia, 70 ft high, cone bottom, closed top, carbon steel
5. Feeder, coal	4	552 tons/hr rotary gate feeder, 2 hp motor, carbon steel
6. Conveyor, coal transfer	1	552 tons/hr, 42 in. belt, 880 ft long, 75 hp motor, carbon steel

(continued)

TABLE A-14 (continued)

Area 8--Raw Material Handling and Preparation

Item	No.	Description
1. Sampler, coal	1	Automatic coal sampler
2. Bin, coal surge	2	3,600 ft^3, 15 ft wide, 15 ft long, 16 ft high, 13 ft deep pyramid bottom, closed top, carbon steel
3. Feeder, weigh belt	2	297 tons/hr, 42 in. belt, 10 ft long, 2 hp motor, carbon steel
4. Crusher, coal	2	297 tons/hr, double roll type, 36 in. dia rolls, 2 each, 25 hp motors, totally enclosed, carbon steel
5. Screen, coal	2	297 tons/hr, 119 ft^2 area, 7 ft x 17 ft, flip flow vibrating screen deck, 40 hp motor, carbon steel
6. Crusher, coal	2	173 tons/hr, double roll type, 30 in. dia rolls, 2 each, 20 hp motors, totally enclosed, carbon steel
7. Conveyor, reactor area feed	1	593 tons/hr, 42 in. belt, 560 ft long, 100 hp motor, with 4 fixed trippers, totally enclosed, carbon steel
8. Pump, NO_2 unloading	2	70 gpm, 415 ft head, positive displacement, 15 hp motor, 316 stainless steel
9. Tank, NO_2 storage	1	17,600 gal, 10 ft dia, 30 ft long, horizontal type, 150 psig operating pressure, 316 stainless steel
10. Pump, binder unloading	2	40 gpm, 50 ft head, centrifugal, 2 hp motor, carbon steel

(continued)

TABLE A-14 (continued)

Item	No.	Description
11. Pump, binder storage	1	887,000 gal, 55 ft dia, 50 ft high, flat bottom, closed top, carbon steel
12. Pump, binder feed	2	20 gpm, 200 ft head, centrifugal, 5 hp motor, carbon steel
13. Pump, NaOH unloading	2	55 gpm, 40 ft head, centrifugal, 1.5 hp motor, neoprene lined, carbon steel
14. Tank, NaOH storage	4	994,000 gal, 59 ft dia, 50 ft high, flat bottom, closed top, neoprene lined, carbon steel
15. Pump, NaOH feed	2	13 gpm, 100 ft head, centrifugal, 1 hp motor, neoprene lined, carbon steel
16. Pump, NaOH feed	2	38 gpm, 100 ft head, centrifugal, 3 hp motor, neoprene lined, carbon steel
17. Pump, NaOH feed	2	28 gpm, 100 ft head, centrifugal, 3 hp motor, neoprene lined, carbon steel
18. Pump, NaOH transfer	2	13 gpm, 100 ft head, centrifugal, 1 hp motor, neoprene lined, carbon steel
19. Tank, 20% NaOH mix	1	25,470 gal, 17 ft dia, 15 ft high, flat bottom, closed top, neoprene lined, carbon steel
20. Agitator, NaOH mix tank	1	15 hp, neoprene coated, carbon steel
21. Pump, 20% NaOH feed	2	52 gpm, 100 ft head, centrifugal, 3 hp motor, neoprene lined, carbon steel
22. Hoist, car shaker	1	2,000 lb capacity, 15 hp motor
23. Shaker, car	1	Railroad, trackside vibrator, 20 hp

(continued)

TABLE A-14 (continued)

Item	No.	Description
24. Puller, car	1	Railroad car puller with base, wire rope, 25 hp motor, 5 hp return motor
25. Hopper, lime unloading	1	94 ft^3, 8 ft 4 in. x 8 ft 4 in. top opening, 3 ft deep pyramid, with 2 ft 4 in. x 2 ft 4 in. bottom opening
26. Feeder, lime vibrating	1	210 tons/hr, 42 in. wide, 5 ft long pan, 2.5 hp vibrator, carbon steel
27. Conveyor, lime unloading	1	210 tons/hr, 24 in. belt, 10 ft long, 2.5 hp motor, carbon steel
28. Conveyor, lime unloading	1	210 tons/hr, 24 in. belt, 381 ft long, 25 hp motor, totally enclosed, carbon steel
29. Tunnel, conveyor	1	6 ft wide, 6 ft high, 70 ft long, steel reinforced concrete
30. Pump, tunnel sump	1	20 gpm, 20 ft head, centrifugal, 0.5 hp motor, carbon steel
31. Silo, lime storage	1	430,000 ft^3, 74 ft dia, 100 ft high, cone bottom, closed top, carbon steel
32. Feeder, weigh belt	1	22 tons/hr, 12 in. belt, 10 ft long, 0.5 hp motor, carbon steel
33. Conveyor, slaker feed	1	22 tons/hr, 12 in. belt, 40 ft long, 0.75 hp motor, carbon steel
34. Slaker, lime	1	105.5 tons/hr of 20% slaked slurry product, 20 ft x 43 ft x 9.5 ft high, 2 hp motor on rake drive, 30 hp mixer
35. Pump, lime slaker product	2	338 gpm, 100 ft head, centrifugal, 20 hp motor, neoprene lined, carbon steel

(continued)

TABLE A-14 (continued)

Item	No.	Description
36. Tank, 20% lime feed	1	25,470 gal, 17 ft dia, 15 ft high, flat bottom, closed top, neoprene lined, carbon steel
37. Agitator, 20% lime feed tank	1	10 hp, neoprene coated, carbon steel
38. Pump, 20% lime feed	2	50 gpm, 100 ft head, centrifugal, 3 hp motor, neoprene lined, carbon steel
39. Tank, 10% lime feed	1	322,400 gal, 38 ft dia, 38 ft high, flat bottom, closed top, neoprene lined, carbon steel
40. Agitator, 10% lime feed tank	1	20 hp, neoprene coated, carbon steel
41. Pump, 10% lime feed	2	647 gpm, 100 ft head, centrifugal, 30 hp motor, neoprene lined, carbon steel

Area 9--Sulfur Oxidation

Item	No.	Description
1. Bin, reactor feed	4	5,670 ft^3, 19 ft dia, 20 ft high, cone bottom, closed top, carbon steel
2. Feeder, weigh belt	4	149 tons/hr, 24 in. belt, 15 ft long, 1 hp motor, carbon steel
3. Reactor, fluidized bed	4	22.3 ft dia, 51 ft high side, cone bottom, cone top, 1 atmosphere operating pressure, 316 stainless steel
4. Fan, scrubber forced draft	4	140,740 aft^3/min at 200°F, ΔP 15 in. H_2O, 450 hp motor, 316 stainless steel

(continued)

TABLE A-14 (continued)

Item	No.	Description
5. Fan, recirculating	4	140,740 aft^3/min at 200^{o}F, ΔP 15 in. H_2O, 450 hp motor, 316 stainless steel
6. Heater, oxidizing gas	4	8,080 ft^2 area, 316 stainless steel
7. "Scrubber," vent gas combustion	1	10 ft x 10 ft natural gas fired NO_2IDIZER, 10 hp blower, 35 ft of stack, carbon steel

Area 10--Reactor Off-Gas Cleaning

Item	No.	Description
1. Scrubber, particulate	4	Venturi, 14.8 ft dia, 52 ft high, with mist eliminator, 316 stainless steel
2. Thickener, fine coal	4	13 ft wide, 22 ft long, 21 ft high, inclined plate gravity settler-thickener with increased volume sludge compartment, 1 hp picket-fence rake
3. Pump, thickener underflow	6	354 gpm, 160 ft head, centrifugal, 40 hp motor, neoprene lined, carbon steel
4. Tank, thickener overflow	4	6,600 gal, 7.5 ft dia, 20 ft high, flat bottom, neoprene lined, carbon steel
5. Pump, venturi feed	6	2,100 gpm, 100 ft head, centrifugal, 100 hp motor, neoprene lined, carbon steel
6. Absorber, SO_2	4	Venturi, 14.8 ft dia, 52 ft high, with mist eliminator, 316 stainless steel

(continued)

TABLE A-14 (continued)

Item	No.	Description
7. Tank, effluent surge	4	16,100 gal, 14 ft dia, 14 ft high, cone bottom, neoprene lined, carbon steel
8. Agitator, effluent surge tank	4	10 hp, neoprene coated, carbon steel
9. Pump, effluent	6	1,570 gpm, 100 ft head, centrifugal, 75 hp motor, neoprene lined, carbon steel
10. Thickener, absorber	4	13 ft wide, 22 ft long, 21 ft high, inclined plate gravity settler-thickener with increased volume sludge compartment, 1 hp picket-fence rake
11. Pump, thickener underflow	6	176 gpm, 100 ft head, centrifugal, 10 hp motor, neoprene lined, carbon steel
12. Tank, thickener overflow neutralizer	4	4,280 gal, 9 ft dia, 9 ft high, cone bottom, neoprene lined, carbon steel
13. Agitator, thickener	4	5 hp, neoprene coated, carbon steel
14. Pump, thickener underflow	6	1,408 gpm, 100 ft head, centrifugal, 75 hp motor, neoprene lined, carbon steel
15. Fan, absorber, forced draft	4	140,740 aft^3/min at 200^{o}F, ΔP 15 in. H_2O, 450 hp motor, 316 stainless steel

Area 11-Fine Coal Leaching

Item	No.	Description
1. Tank, water leach	4	3,600 gal, 8.5 ft dia, 8.5 ft high, cone bottom, closed top, neoprene lined, carbon steel
2. Agitator, water leach tank	4	10 hp, neoprene coated, carbon steel

(continued)

TABLE A-14 (continued)

Item	No.	Description
3. Pump, cyclone feed	6	722 gpm, 260 ft head, centrifugal, 125 hp motor, carbon steel
4. Cyclone, water leach	36	90 gpm, 6 in. dia, heavy duty cyclone, 100 psig operating pressure, high density gum rubber-lined cast iron and steel
5. Tank, cyclone underflow	4	1,614 gal, 6.5 ft dia, 6.5 ft high, cone bottom, closed top, neoprene lined, carbon steel
6. Agitator, cyclone underflow tank	4	5 hp, neoprene coated, carbon steel
7. Heater, process water	4	178 ft^2 area, carbon steel
8. Pump, cyclone feed	6	523 gpm, 260 ft head, centrifugal, 100 hp motor, carbon steel
9. Cyclone, water leach	24	90 gpm, 6 in. dia, heavy duty cyclone, 100 psig operating pressure, high density gum rubber-lined cast iron and steel
10. Tank, cyclone underflow	4	3,600 gal, 8.5 ft dia, 8.5 ft high, flat bottom, closed top, neoprene lined, carbon steel
11. Agitator, cyclone underflow tank	4	10 hp, neoprene coated, carbon steel
12. Pump, cyclone feed	6	752 gpm, 260 ft head, centrifugal, 125 hp motor, carbon steel
13. Cyclone, caustic leach	36	90 gpm, 6 in. dia, heavy duty cyclone, 100 psig operating pressure, high density gum rubber-lined cast iron and steel
14. Tank, cyclone underflow	4	850 gal, 5.25 ft dia, 5.25 ft high, flat bottom, closed top, neoprene lined, carbon steel

(continued)

TABLE A-14 (continued)

Item	No.	Description
15. Agitator, cyclone underflow tank	4	10 hp, neoprene coated, carbon steel
16. Pump, slurry transfer	6	85 gpm, 100 ft head, centrifugal, 15 hp motor, neoprene lined, carbon steel
17. Thickener, fine coal	4	10 ft wide, 19 ft long, 21 ft high, inclined plate gravity settler-thickener with increased volume sludge compartment, 1 hp picket-fence rake
18. Pump, thickener underflow	6	3.5 gpm, 100 ft head, centrifugal, 0.25 hp motor, neoprene lined, carbon steel
19. Tank, thickener overflow	4	2,000 gal, 7 ft dia, 7 ft high, flat bottom, neoprene lined, carbon steel
20. Pump, thickener overflow	6	667 gpm, 100 ft head, centrifugal, 30 hp motor, neoprene lined, carbon steel
21. Tank, leach mix	4	7,800 gal, 11 ft dia, 11 ft high, cone bottom, closed top, neoprene lined, carbon steel
22. Agitator, leach mix tank	4	5 hp, neoprene coated, carbon steel
23. Pump, cyclone feed	6	758 gpm, 260 ft head, centrifugal, 125 hp motor, carbon steel
24. Cyclone, water wash	36	90 gpm, 6 in. dia, heavy duty cyclone, 100 psig operating pressure, high density gum rubber-lined cast iron and steel
25. Tank, cyclone underflow	4	3,800 gal, 8.5 ft dia, 9 ft high, cone bottom, closed top, neoprene lined, carbon steel
26. Agitator, cyclone underflow tank	4	10 hp, neoprene coated, carbon steel

(continued)

TABLE A-14 (continued)

Item	No.	Description
27. Pump, cyclone feed	6	758 gpm, 260 ft head, centrifugal, 125 hp motor, carbon steel
28. Cyclone, water wash	36	90 gpm, 6 in. dia, heavy duty cyclone, 100 psig operating pressure, high density gum rubber-lined cast iron and steel
29. Tank, cyclone underflow	4	3,800 gal, 8.5 ft dia, 9 ft high, cone bottom, closed top, neoprene lined, carbon steel
30. Agitator, cyclone underflow tank	4	10 hp, neoprene coated, carbon steel
31. Pump, cyclone feed	6	758 gpm, 260 ft head, centrifugal, 125 hp motor, carbon steel
32. Cyclone, wash water	36	90 gpm, 6 in. dia, heavy duty cyclone, 100 psig operating pressure, high density gum rubber-lined cast iron and steel
33. Tank, cyclone underflow	4	1,270 gal, 6 ft dia, 6 ft high, cone bottom, closed top, neoprene lined, carbon steel
34. Agitator, cyclone underflow tank	4	10 hp, neoprene coated, carbon steel
35. Pump, centrifugal feed	6	437 gpm, 100 ft head, centrifugal, 30 hp motor, neoprene lined, carbon steel
36. Heater, process water	4	144 ft^2 area, carbon steel
37. Heater, process water	4	102 ft^2 area, carbon steel
38. Centrifuge, fine coal	4	44 in. dia, 132 in. long, continuous screen bowl type, 200 hp motor

(continued)

TABLE A-14 (continued)

Item	No.	Description
39. Tank, centrate	4	2,000 gal, 7 ft dia, 7 ft high, cone bottom, closed top, carbon steel
40. Pump, centrate return	6	670 gpm, 100 ft head, centrifugal, 30 hp motor, carbon steel
41. Conveyor, centrifuge product	1	209 tons/hr, 30 in. belt, 160 ft long, 5 hp motor, carbon steel
42. Conveyor, centrifuge product	1	209 tons/hr, 30 in. belt, 180 ft long, 5 hp motor, carbon steel
43. Sampler, coal	1	Automatic coal sampler
44. Elevator, bucket	2	105 tons/hr, 40 ft high, 16 in. x 8 in. x 11-3/4 in. continuous buckets, belt drive, 7.5 hp motor, carbon steel

Area 12--Coarse Coal Leaching

Item	No.	Description
1. Dewaterer, water leach	4	100 tons/hr, single screw, spiral dewaterer, 54 in. dia flights, 34 ft tube length, 40 hp motor, closed top, carbon steel
2. Pump, overflow	6	347 gpm, 100 ft head, centrifugal, 20 hp motor, neoprene lined, carbon steel
3. Dewaterer, water leach	4	100 tons/hr, single screw spiral dewaterer, 54 in. dia flights, 34 ft tube length, 40 hp motor, carbon steel
4. Pump, dewaterer overflow	6	406 gpm, 100 ft head, centrifugal, 20 hp motor, neoprene lined, carbon steel

(continued)

TABLE A-14 (continued)

Item	No.	Description
5. Heater, process water	4	163 ft^2 area, carbon steel
6. Tank, caustic leach	4	10,000 gal, 12 ft dia, 12 ft high, cone bottom, closed top, neoprene lined, carbon steel
7. Agitator, caustic leach tank	4	10 hp, neoprene coated, carbon steel
8. Pump, thickener feed	6	980 gpm, 100 ft head, centrifugal, 60 hp motor, neoprene lined, carbon steel
9. Thickener, coarse coal	4	10 ft wide, 19 ft long, 21 ft high, inclined plate gravity settler-thickener with increased volume sludge compartment, 1 hp picket-fence rake
10. Pump, thickener underflow	6	641 gpm, 100 ft head, centrifugal, 50 hp motor, neoprene lined, carbon steel
11. Tank, thickener overflow	4	975 gal, 5.5 ft dia, 5.5 ft high, flat bottom, closed top, neoprene lined, carbon steel
12. Pump, thickener overflow	6	339 gpm, 100 ft head, centrifugal, 20 hp motor, neoprene lined, carbon steel
13. Tank, caustic leach	4	6,460 gal, 10 ft dia, 11 ft high, flat bottom, closed top, neoprene lined, carbon steel
14. Agitator, caustic leach tank	4	5 hp, neoprene coated, carbon steel
15. Dewaterer, water wash	4	100 tons/hr, single screw spiral dewaterer, 54 in. dia flights, 34 ft tube length, 40 hp motor, closed top, carbon steel
16. Pump, dewaterer overflow	6	900 gpm, 100 ft head, centrifugal, 40 hp motor, neoprene lined, carbon steel

(continued)

TABLE A-14 (continued)

	Item	No.	Description
17.	Dewaterer, water wash	4	100 tons/hr, single screw spiral dewaterer, 54 in. dia flights, 34 ft tube length, 40 hp motor, closed top, carbon steel
18.	Pump, dewaterer overflow	6	336 gpm, 100 ft head, centrifugal, 15 hp motor, neoprene lined, carbon steel
19.	Dewaterer, water wash	4	100 tons/hr, single screw spiral dewaterer, 54 in. dia flights, 34 ft tube length, 40 hp motor, closed top, carbon steel
20.	Pump, dewaterer overflow	6	336 gpm, 100 ft head, centrifugal, 15 hp motor, neoprene lined, carbon steel
21.	Tank, water wash	4	1,070 gal, 5.5 ft dia, 6 ft high, cone bottom, closed top, neoprene lined, carbon steel
22.	Agitator, water wash tank	4	10 hp, neoprene coated, carbon steel
23.	Heater, process water	4	58 ft^2 area, carbon steel
24.	Pump, centrifuge feed	6	230 gpm, 100 ft head, centrifugal, 25 hp motor, neoprene lined, carbon steel
25.	Heater, process water	4	58 ft^2 area, carbon steel
26.	Centrifuge, coarse coal	4	230 gpm, continuous oscillating bowl, 25 hp motor and 5 hp motor
27.	Tank, centrate	4	1,070 gal, 5.5 ft dia, 6 ft high, flat bottom, closed top, carbon steel
28.	Pump, centrate return	6	336 gpm, 100 ft head, centrifugal, 15 hp motor, carbon steel
29.	Conveyor, centrifuge product	1	384 tons/hr, 30 in. belt, 160 ft long, 5 hp motor, carbon steel

(continued)

TABLE A-14 (continued)

Item	No.	Description
30. Sampler, coal	1	Automatic coal sampler
31. Conveyor, coarse coal bleed	1	56 tons/hr, 18 in. belt, 50 ft long, 5 hp motor, carbon steel
32. Conveyor, stacker feed	1	596 tons/hr, 42 in. belt, 715 ft long, 50 hp motor, carbon steel
33. Elevator, coal dryer feed	8	100 tons/hr, 96 ft high, 24 in. x 8 in. x 11-3/4 in. continuous buckets, double chain drive, 20 hp motor, carbon steel
34. Elevator, coal mix bin feed	2	134 tons/hr, 40 ft high, 20 in. x 8 in. x 11-3/4 in. continuous buckets, belt drive, 7.5 hp motor, carbon steel

Area 13--Product Agglomeration and Handling

Item	No.	Description
1. Bin, coal mix	1	1,725 ft^3, 13 ft dia, 13 ft high, cone bottom, carbon steel
2. Feeder, coal	1	266 tons/hr, 30 in. belt, 5 ft long, 1.5 hp motor, carbon steel
3. Conveyor, coal transfer	1	266 tons/hr, 30 in. belt, 200 ft long, 40 hp motor, 11 fixed trippers, carbon steel
4. Pelletizing plants	11	25 tons/hr package pelletizing plants including 23 ft dia pan pelletizer, dryers and all support systems

(continued)

TABLE A-14 (continued)

Item	No.	Description
5. Conveyor, pelletizer product	1	125 tons/hr, 24 in. belt, 185 ft long, 2 hp motor, carbon steel
6. Conveyor, pelletizer product	1	125 tons/hr, 24 in. belt, 130 ft long, 2 hp motor, carbon steel
7. Conveyor, stacker	2	596 tons/hr, 42 in. belt, 968 ft long, 25 hp motor, traveling tripper, carbon steel
8. Hopper, pile reclaim	20	13 ft x 13 ft top opening, 3 ft deep pyramid, with 22 in. x 22 in. bottom opening, carbon steel
9. Feeders, vibrating pan	20	120 tons/hr, 24 in. wide, 42 in. long pan, 1.5 hp vibrator, carbon steel
10. Conveyor, coal transfer	2	1,000 tons/hr, 42 in. belt, 970 ft long, 40 hp motor, carbon steel
11. Tunnel, conveyor	2	7 ft wide, 6 ft deep, 970 ft long, steel-reinforced concrete
12. Tunnel, conveyor	1	7 ft wide, 6 ft deep, 320 ft long, steel-reinforced concrete
13. Pump, tunnel sump	3	60 gpm, 30 ft head, centrifugal, 1 hp motor, carbon steel

Area 14--Leach Solution Neutralization and Water Handling

Item	No.	Description
1. Tank, neutralizer stage 1	4	25,600 gal, 16 ft dia, 17 ft high, flat bottom, closed top, neoprene lined, carbon steel
2. Agitator, neutralizer stage 1 tank	4	10 hp, neoprene coated, carbon steel

(continued)

TABLE A-14 (continued)

Item	No.	Description
3. Tank, neutralizer stage 2	4	8,500 gal, 11 ft dia, 12 ft high, flat bottom, closed top, neoprene lined, carbon steel
4. Agitator, neutralizer stage 2 tank	4	10 hp, neoprene coated, carbon steel
5. Tank, neutralizer stage 3	4	8,500 gal, 11 ft dia, 12 ft high, flat bottom, closed top, neoprene lined, carbon steel
6. Agitator, neutralizer stage 3 tank	4	10 hp, neoprene coated, carbon steel
7. Tank, neutralizer stage 4	4	8,500 gal, 11 ft dia, 12 ft high, flat bottom, closed top, neoprene lined, carbon steel
8. Agitator, neutralizer stage 4 tank	4	10 hp, neoprene coated, carbon steel
9. Pump, pond feed	2	11,480 gpm, 300 ft head, centrifugal, 1,750 hp motor, neoprene lined, carbon steel
10. Pipeline, pond feed	2	30 in. dia, 5,280 ft long, rubber lined, carbon steel
11. Pump, pond return	2	11,156 gpm, 300 ft head, centrifugal, 1,500 hp motor, carbon steel
12. Pipeline, pond return	1	30 in. dia, 5,280 ft long, carbon steel
13. Tank, recycle water	1	5,400,000 gal, 150 ft dia, 41 ft high, flat bottom, carbon steel
14. Pump, water feed	2	4,184 gpm, 100 ft head, centrifugal, 200 hp motor, carbon steel
15. Pump, water feed	2	697 gpm, 100 ft head, centrifugal, 30 hp motor, carbon steel
16. Pump, water feed	2	39 gpm, 100 ft head, centrifugal, 2 hp motor, carbon steel

(continued)

TABLE A-14 (continued)

Item	No.	Description
17. Pump, water feed	2	1,152 gpm, 100 ft head, centrifugal, 50 hp motor, carbon steel
18. Pump, water feed	2	2,441 gpm, 100 ft head, centrifugal, 125 hp motor, carbon steel
19. Pump, water feed	2	1,624 gpm, 100 ft head, centrifugal, 75 hp motor, carbon steel
20. Pump, water feed	2	1,771 gpm, 100 ft head, centrifugal, 75 hp motor, carbon steel
21. Pump, makeup water	2	752 gpm, 100 ft head, centrifugal, 40 hp motor, carbon steel

Area 15--Settling Pond

Item	No.	Description
1. Pond	1	932 acres, 25.58 ft deep, with clay lining

APPENDIX B

ECONOMIC DATA

TABLE B-1. PCC 1 PROCESS

TOTAL CAPITAL INVESTMENT

(Dense-medium vessel, dense-
medium cyclone, froth flotation)

Case variation - 0.7% S coal

	Investment, $
Direct Investment	
Coal receiving and storage	8,799,000
Raw coal sizing	1,616,000
Coarse coal cleaning	1,575,000
Intermediate coal cleaning	2,234,000
Fine coal cleaning	2,696,000
Refuse disposal as landfill	1,904,000
Clean coal storage	8,459,000
Total areas	27,283,000
Services, utilities, and miscellaneous	1,637,000
Total direct investment	28,920,000
Indirect Investment	
Engineering design and supervision	2,429,000
Architect and engineering contractor	578,000
Construction expense	3,441,000
Contractor fees	972,000
Total indirect investment	7,420,000
Contingency	5,451,000
Total fixed investment	41,791,000
Other Capital Charges	
Allowance for startup and modifications	4,179,000
Interest during construction	5,851,000
Total depreciable investment	51,821,000
Land	2,174,000
Working capital	10,696,000
Total capital investment	64,691,000
Dollars of total capital per kW of generating capacity	32.35

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.

Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-2. PCC I PROCESS

ANNUAL REVENUE REQUIREMENTS

(Dense-medium vessel, dense-
mediun cyclone, froth flotation)

Case variation - 0.7% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	283,400 tons	31.58/ton	8,949,000
Total raw materials cost			8,949,000
Conversion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	47,600 kgal	0.13/kgal	6,000
Electricity	14,900,000 kWh	0.039/kWh	581,000
Diesel fuel	97,000 gal	0.70/gal	68,000
Process material: magnetite, Grade E	2,720 tons	93.31/ton	254,000
Maintenance, 6% of direct investment			1,735,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			4,706,000
Total direct costs			13,655,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,109,000
Average cost of capital and taxes at 8.6% of total capital investment			5,563,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			-
Total indirect costs			9,864,000
Gross annual revenue requirements			23,519,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			23,519,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	2.14	188

Basis
Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30-years; operating time, 6,000 hr/yr.
Clean coal production capacity for 2,000 MW-coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
Total direct investment, $28,920,000; total depreciable investment, $51,821,000; and total capital investment, $64,691,000.
Raw coal (moisture-free): 4,777,000 tons/yr, 0.7% sulfur, 1.5% ash, 1,700 Btu/lb, and 0.6 lb S/MBtu.
Clean coal (moisture-free): 4,354,000 tons/yr, 0.62% sulfur, 7.83% ash, 12,200 Btu/lb, and 0.51 lb S/MBtu.

TABLE B-3. PCC 1 PROCESS

TOTAL CAPITAL INVESTMENT

(Dense-medium vessel, dense-medium cyclone, froth flotation)

Case variation - 2% S coal	Investment, $
Direct Investment	
Coal receiving and storage	8,529,000
Raw coal sizing	1,543,000
Coarse coal cleaning	1,512,000
Intermediate coal cleaning	2,132,000
Fine coal cleaning	2,573,000
Refuse disposal as landfill	2,558,000
Clean coal storage	8,028,000
Total areas	26,875,000
Services, utilities, and miscellaneous	1,613,000
Total direct investment	28,488,000
Indirect Investment	
Engineering design and supervision	2,393,000
Architect and engineering contractor	570,000
Construction expense	3,390,000
Contractor fees	957,000
Total indirect investment	7,310,000
Contingency	5,370,000
Total fixed investment	41,168,000
Other Capital Charges	
Allowance for startup and modifications	4,117,000
Interest during construction	5,764,000
Total depreciable investment	51,049,000
Land	3,008,000
Working capital	8,829,000
Total capital investment	62,886,000
Dollars of total capital per kW of generating capacity	31.44

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.

Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-4. PCC 1 PROCESS

ANNUAL REVENUE REQUIREMENTS

(Dense-medium vessel, dense-medium cyclone, froth flotation)

Case variation - 2% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	315,600 tons	31.58/ton	9,966,000
Total raw materials cost			9,966,000
Converstion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	39,600 kgal	0.13/kgal	5,000
Electricity	14,108,000 kWh	0.039/kWh	550,000
Diesel fuel	119,000 gal	0.70/gal	83,000
Process material: magnetite, Grade E	2,490 tons	93.31/ton	232,000
Maintenance, 6% of direct investment			1,709,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			4,641,000
Total direct costs			14,607,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,063,000
Average cost of capital and taxes at 8.6% of total capital investment			5,408,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			-
Total indirect costs			9,663,000
Gross annual revenue requirements			24,270,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			24,270,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	2.21	33.5

Basis
Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 6,000 hr/yr.
Clean-coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
Total direct investment, $28,488,000; total depreciable investment, $51,049,000; and total capital investment, $62,886,000.
Raw coal (moisture-free): 4,362,000 tons/yr, 2% sulfur, 14.5% ash, 12,800 Btu/lb, and 1.56 lb S/MBtu.
Clean coal (moisture-free): 3,749,000 tons/yr, 1.36% sulfur, 7.45% ash, 14,000 Btu/lb, and 0.97 lb S/MBtu.

TABLE B-5. PCC I PROCESS

TOTAL CAPITAL INVESTMENT

(Dense-medium vessel, dense-medium cyclone, froth flotation)

Case variation - 3.5% S coal

	Investment, $
Direct Investment	
Coal receiving and storage	8,608,000
Raw coal sizing	1,564,000
Coarse coal cleaning	1,547,000
Intermediate coal cleaning	2,162,000
Fine coal cleaning	2,594,000
Refuse disposal as landfill	2,581,000
Clean coal storage	8,048,000
Total areas	27,104,000
Services, utilities, and miscellaneous	1,626,000
Total direct investment	28,730,000
Indirect Investment	
Engineering design and supervision	2,413,000
Architect and engineering contractor	575,000
Construction expense	3,419,000
Contractor fees	965,000
Total indirect investment	7,372,000
Contingency	5,415,000
Total fixed investment	41,517,000
Other Capital Charges	
Allowance for startup and modifications	4,152,000
Interest during construction	5,812,000
Total depreciable investment	51,481,000
Land	3,034,000
Working capital	9,110,000
Total capital investment	63,625,000
Dollars of total capital per kW of generating capacity	31.81

Basis
Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.
Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.
Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-6. PCC I PROCESS

ANNUAL REVENUE REQUIREMENTS

(Dense-medium vessel, dense-
mediun cyclone, froth flotation)

Case variation - 3.5% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	368,650 tons	31.58/ton	11,642,000
Total raw materials cost			11,642,000
Conversion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	39,600 kgal	0.13/kgal	5,000
Electricity	14,337,000 kWh	0.039/kWh	559,000
Diesel fuel	121,000 gal	0.70/gal	85,000
Process material: magnetite, Grade E	2,550 tons	93.31/ton	238,000
Maintenance, 6% of direct investment			1,723,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			4,672,000
Total direct costs			16,314,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,089,000
Average cost of capital and taxes at 8.6% of total capital investment			5,472,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			-
Total indirect costs			9,753,000
Gross annual revenue requirements			26,067,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			26,067,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	2.37	22.3

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 6,000 hr/yr.

Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $28,730,000; total depreciable investment, $51,481,000; and total capital investment, $63,625,000.

Raw coal (moisture-free): 4,480,000 tons/yr, 3.5% sulfur, 14.0% ash, 12,500 Btu/lb, and2.79 lb S/MBtu.

Clean coal (moisture-free): 3,862,000 tons/yr, 2.55% sulfur, 7.99% ash, 13,400 Btu/lb, and 1.91 lb S/MBtu.

TABLE B-7. PCC I PROCESS

TOTAL CAPITAL INVESTMENT

(Dense-medium vessel, dense-medium cyclone, froth flotation)

Base case - 5% S coal	Investment, $
Direct Investment	
Coal receiving and storage	8,841,000
Raw coal sizing	1,627,000
Coarse coal cleaning	1,585,000
Intermediate coal cleaning	2,249,000
Fine coal cleaning	2,696,000
Refuse disposal as landfill	3,058,000
Clean coal storage	8,261,000
Total areas	28,317,000
Services, utilities, and miscellaneous	1,699,000
Total direct investment	30,016,000
Indirect Investment	
Engineering design and supervision	2,521,000
Architect and engineering contractor	600,000
Construction expense	3,572,000
Contractor fees	1,009,000
Total indirect investment	7,702,000
Contingency	5,658,000
Total fixed investment	43,376,000
Other Capital Charges	
Allowance for startup and modifications	4,337,000
Interest during construction	6,073,000
Total depreciable investment	53,786,000
Land	3,686,000
Working capital	9,946,000
Total capital investment	67,418,000
Dollars of total capital per kW of generating capacity	33.71

Basis
- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.
- Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.
- Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-8. PCC I PROCESS

ANNUAL REVENUE REQUIREMENTS

(Dense-medium vessel, dense-
medium cyclone, froth flotation)

	Base case - 5% S coal		
	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	478,100 tons	31.58/ton	15,098,000
Total raw materials cost			15,098,000
Conversion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	45,300 kgal	0.13/kgal	6,000
Electricity	15,110,000 kWh	0.039/kWh	589,000
Diesel fuel	145,000 gal	0.70/gal	102,000
Process material: magnetite, Grade E	2,760 tons	93.31/ton	257,000
Maintenance, 6% of direct investment			1,801,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			4,817,000
Total direct costs			19,915,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,227,000
Average cost of capital and taxes at 8.6% of total capital investment			5,798,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			-
Total indirect costs			10,217,000
Gross annual revenue requirements			30,132,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			30,132,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	2.74	16.3

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 6,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $30,016,000; total depreciable investment, $53,786,000; and total capital investment, $67,418,000.

Raw coal (moisture-free): 4,840,000 tons/yr, 5% sulfur, 16.7% ash, 12,000 Btu/lb, and 4.17 lb S/MBtu.

Clean coal (moisture-free): 4,073,000 tons/yr, 3.67% sulfur, 10.09% ash, 13,000 Btu/lb, and 2.84 lb S/MBtu.

TABLE B-9. PCC II PROCESS

TOTAL CAPITAL INVESTMENT

(Low-gravity D.M. cyclone, high-gravity
D.M. cyclone, froth flotation)

Case variation - 0.7% S coal

	Investment, $
Direct Investment	
Coal receiving and storage	8,821,000
Raw coal sizing	1,839,000
Low-gravity cleaning	3,553,000
High-gravity cleaning	1,631,000
Fine coal cleaning	4,691,000
Refuse disposal as landfill	1,956,000
Clean coal storage	6,758,000
Middling coal storage	4,623,000
Total areas	33,872,000
Services, utilities, and miscellaneous	2,032,000
Total direct investment	35,904,000
Indirect Investment	
Engineering design and supervision	3,016,000
Architect and engineering contractor	718,000
Construction expense	4,273,000
Contractor fees	1,206,000
Total indirect investment	9,213,000
Contingency	6,768,000
Total fixed investment	51,885,000
Other Capital Charges	
Allowance for startup and modifications	5,119,000
Interest during construction	7,264,000
Total depreciable investment	64,268,000
Land	2,251,000
Working capital	10,843,000
Total capital investment	77,362,000
Dollars of total capital per kW of generating capacity	38.68

Basis
- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.
- Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.
- Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-10. PCC II PROCESS

ANNUAL REVENUE REQUIREMENTS

(Low-gravity D.M. cyclone, high-gravity
D.M. cyclone, froth flotation)

Case variation - 0.7% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	295,200 tons	31.58/ton	9,322,000
Total raw materials cost			9,322,000
Conversion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	93,600 kgal	0.13/kgal	12,000
Electricity	27,269,000 kWh	0.039/kWh	1,064,000
Diesel fuel	116,000 gal	0.70/gal	81,000
Process material: magnetite, Grade E	2,900 tons	93.31/ton	271,000
Maintenance, 6% of direct investment			2,154,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			5,644,000
Total direct costs			14,966,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,856,000
Average cost of capital and taxes at 8.6% of total capital investment			6,653,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			–
Total indirect costs			11,701,000
Gross annual revenue requirements			26,667,000
Byproduct Sales Revenue			
None			–
Total annual revenue requirements			26,667,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	2.42	197.6

Basis

Midwest location of coal-cleaning plant: time basis for scaling, mid-1982; plant life, 30 years; operating time, 6,000 hr/yr.

Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $35,904,000; total depreciable investment, $64,268,000; total capital investment, $77,362,000.

Raw coal (moisture-free): 4,787,000 ton/yr, 0.7% sulfur, 11.5% ash, 11,700 Btu/lb, and 0.60 lb S/MBtu.

Clean coal (moisture-free): 4,350,000 ton/yr, 0.62% sulfur, 7.44% ash, 12,200 Btu/lb, and 0.51 lb S/MBtu.

TABLE B-11. PCC II PROCESS

TOTAL CAPITAL INVESTMENT

(Low-gravity D.M. cyclone, high-gravity
D.M. cyclone, froth flotation)

Case variation - 2% S coal	Investment, $
Direct Investment	
Coal receiving and storage	8,560,000
Raw coal sizing	1,751,000
Low-gravity cleaning	3,404,000
High-gravity cleaning	1,588,000
Fine coal cleaning	4,504,000
Refuse disposal as landfill	2,621,000
Clean coal storage	6,482,000
Middling coal storage	4,345,000
Total areas	33,255,000
Services, utilities, and miscellaneous	1,995,000
Total direct investment	35,250,000
Indirect Investment	
Engineering design and supervision	2,961,000
Architect and engineering contractor	705,000
Construction expense	4,195,000
Contractor fees	1,184,000
Total indirect investment	9,045,000
Contingency	6,644,000
Total fixed investment	50,939,000
Other Capital Charges	
Allowance for startup and modifications	5,094,000
Interest during construction	7,131,000
Total depreciable investment	63,164,000
Land	3,117,000
Working capital	8,989,000
Total capital investment	75,270,000
Dollars of total capital per kW of generating capacity	37.64

Basis
- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.
- Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.
- Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-12. PCC II PROCESS

ANNUAL REVENUE REQUIREMENTS

(Low-gravity D.M. cyclone, high-gravity D.M. cyclone, froth flotation)

Case variation - 2% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	339,100 tons	31.58/ton	10,709,000
Total raw materials cost			10,709,000
Conversion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	76,200 kgal	0.13/kgal	10,000
Electricity	25,869,000 kWh	0.039/kWh	1,009,000
Diesel fuel	123,000 gal	0.70/gal	86,000
Process material: magnetite, Grade E	2,650 tons	93.31/ton	247,000
Maintenance, 6% of direct investment			2,115,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			5,529,000
Total direct costs			16,238,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,790,000
Average cost of capital and taxes at 8.6% of total capital investment			6,473,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			-
Total indirect costs			11,455,000
Gross annual revenue requirements			27,693,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			27,693,000

	Mills/kWh	c/lb sulfur removed
Equivalent unit revenue requirements	2.52	36.5

Basis

Midwest location of coal-cleaning plant; time basis for scaling, mid-1982; plant life, 30 years; operating time, 6,000 hr/yr.

Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $35,250,000; total depreciable investment, $63,164,000; total capital investment, $75,270,000.

Raw coal (moisture-free): 4,384,000 ton/yr, 2% sulfur, 14.5% ash, 12,800 Btu/lb, 1.56 lb S/MBtu.

Clean coal (moisture-free): 3,747,000 ton/yr, 1.33% sulfur, 7.12% ash, 13,900 Btu/lb, and 0.96 lb S/MBtu.

TABLE B-13. PCC II PROCESS

TOTAL CAPITAL INVESTMENT

(Low-gravity D.M. cyclone, high-gravity
D.M. cyclone, froth flotation)

Case variation - 3.5% S coal

	Investment, $
Direct Investment	
Coal receiving and storage	8,635,000
Raw coal sizing	1,776,000
Low-gravity cleaning	3,448,000
High-gravity cleaning	1,654,000
Fine coal cleaning	4,552,000
Refuse disposal as landfill	2,513,000
Clean coal storage	6,432,000
Middling coal storage	4,463,000
Total areas	33,473,000
Services, utilities, and miscellaneous	2,008,000
Total direct investment	35,481,000
Indirect Investment	
Engineering design and supervision	2,980,000
Architect and engineering contractor	710,000
Construction expense	4,222,000
Contractor fees	1,192,000
Total indirect investment	9,104,000
Contingency	6,688,000
Total fixed investment	51,273,000
Other Capital Charges	
Allowance for startup and modifications	5,127,000
Interest during construction	7,178,000
Total depreciable investment	63,578,000
Land	3,124,000
Working capital	9,265,000
Total capital investment	75,967,000
Dollars of total capital per kW of generating capacity	37.98

Basis

- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.
- Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.
- Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-14. PCC II PROCESS

ANNUAL REVENUE REQUIREMENTS

(Low-gravity D.M. cyclone, high-gravity D.M. cyclone, froth flotation)

Case variation - 3.5% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	388,600 tons	31.58/ton	12,272,000
Total raw materials cost			12,272,000
Conversion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	71,000 kgal	0.13/kgal	9,000
Electricity	26,273,000 kWh	0.039/kWh	1,025,000
Diesel fuel	124,000 gal	0.70/gal	87,000
Process material: magnetite Grade E	2,720 tons	93.31/ton	254,000
Maintenance, 6% of direct investment			2,129,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			5,566,000
Total direct costs			17,838,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,815,000
Average cost of capital and taxes at 8.6% of total capital investment			6,542,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			-
Total indirect costs			11,549,000
Gross annual revenue requirements			29,387,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			29,387,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	2.67	24.1

Basis

- Midwest location of coal-cleaning plant; time basis for scaling, mid-1982; plant life, 30 years, operating time, 6,000 hr/yr.
- Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $35,481,000; total depreciable investment, $63,578,000; total capital investment, $75,967,000.
- Raw coal (moisture-free): 4,499,000 ton/yr, 3.5% sulfur, 14.0% ash, 12,500 Btu/lb, and 2.8 lb S/MBtu.
- Clean coal (moisture-free): 3,860,000 ton/yr, 2.50% sulfur, 7.68% ash, 13,400 Btu/lb, and 1.86 lb S/MBtu.

TABLE B-15. PCC II PROCESS

TOTAL CAPITAL INVESTMENT

(Low-gravity D.M. cyclone, high-gravity
D.M. cyclone, froth flotation)

Base case - 5% S coal

	Investment, $
Direct Investment	
Coal receiving and storage	8,841,000
Raw coal sizing	1,845,000
Low-gravity cleaning	3,564,000
High-gravity cleaning	1,782,000
Fine coal cleaning	4,706,000
Refuse disposal as landfill	3,058,000
Clean coal storage	6,397,000
Middling coal storage	4,632,000
Total areas	34,825,000
Services, utilities, and miscellaneous	2,090,000
Total direct investment	36,915,000
Indirect Investment	
Engineering design and supervision	3,101,000
Architect and engineering contractor	738,000
Construction expense	4,393,000
Contractor fees	1,240,000
Total indirect investment	9,472,000
Contingency	6,958,000
Total fixed investment	53,345,000
Other Capital Charges	
Allowance for startup and modifications	5,335,000
Interest during construction	7,468,000
Total depreciable investment	66,148,000
Land	3,703,000
Working capital	10,033,000
Total capital investment	79,884,000
Dollars of total capital per kW of generating capacity	39.94

Basis
- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.
- Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.
- Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-16. PCC II PROCESS

ANNUAL REVENUE REQUIREMENTS

(Low-gravity D.M. cyclone, high-gravity
D.M. cyclone, froth flotation)

Base case - 5% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	458,650 tons	31.58/ton	14,484,000
Total raw materials cost			14,484,000
Conversion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	85,800 kgal	0.13/kgal	11,000
Electricity	27,384,000 kWh	0.039/kWh	1,068,000
Diesel fuel	148,000 gal	0.70/gal	104,000
Process material, magnetite, Grade E	2,920 tons	93.31/ton	272,000
Maintenance, 6% of direct investment			2,215,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			5,732,000
Total direct costs			20,216,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,969,000
Average cost of capital and taxes at 8.6% of total capital investment			6,870,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			-
Total indirect costs			12,031,000
Gross annual revenue requirements			32,247,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			32,247,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	2.93	16.3

Basis
- Midwest location of coal-cleaning plant; time basis for scaling, mid-1982; plant life, 30 years; operating time, 6,000 hr/yr.
- Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $36,915,000; total depreciable investment, $66,148,000; total capital investment, $79,384,000.
- Raw coal (moisture-free): 4,820,000 ton/yr, 5% sulfur, 16.7% ash, 12,000 Btu/lb, and 4.17 lb S/MBtu.
- Clean coal (moisture-free): 4,049,000 ton/yr, 3.51% sulfur, 9.25% ash, 13,100 Btu/lb, and 2.68 lb S/MBtu.

TABLE B-17. PCC III PROCESS

TOTAL CAPITAL INVESTMENT

(Dense-medium cyclone, concentrating table)

Case variation - 0.7% S coal

	Investment, $
Direct Investment	
Coal receiving and storage	8,822,000
Raw coal sizing	2,430,000
Coarse coal cleaning	3,898,000
Fine coal cleaning	7,828,000
Refuse disposal as landfill	1,966,000
Clean coal storage	8,453,000
Total areas	33,397,000
Services, utilities, and miscellaneous	2,004,000
Total direct investment	35,401,000
Indirect Investment	
Engineering design and supervision	2,974,000
Architect and engineering contractor	708,000
Construction expense	4,213,000
Contractor fees	1,189,000
Total indirect investment	9,084,000
Contingency	6,673,000
Total fixed investment	51,158,000
Other Capital Charges	
Allowance for startup and modifications	5,116,000
Interest during construction	7,162,000
Total depreciable investment	63,436,000
Land	2,264,000
Working capital	10,829,000
Total capital investment	76,529,000
Dollars of total capital per kW of generating capacity	38.26

Basis
- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.
- Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.
- Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-18. PCC III PROCESS

ANNUAL REVENUE REQUIREMENTS

(Dense-medium cyclone, concentrating table)

Case variation - 0.7% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	307,500 tons	31.58/ton	9,711,000
Total raw materials cost			9,711,000
Conversion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	27,900 kgal	0.13/kgal	4,000
Electricity	13,408,000 kWh	0.039/kWh	523,000
Diesel fuel	97,000 gal	0.70/gal	68,000
Process material; magnetite, Grade E	1,950 tons	93.31/ton	182,000
Maintenance, 6% of direct investment			2,124,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			4,963,000
Total direct costs			14,674,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,806,000
Average cost of capital and taxes at 8.6% of total capital investment			6,581,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			-
Total indirect costs			11,579,000
Gross annual revenue requirements			26,253,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			26,253,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	2.39	212.0

Basis
- Midwest location of coal-cleaning plant; time basis for scaling, mid-1982; plant life, 30 years; operating time, 6,000 hr/yr.
- Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $35,401,000; total depreciable investment, $63,436,000; total capital investment, $76,529,000.
- Raw coal (moisture-free): 4,825,000 ton/yr, 0.7% sulfur, 11.5% ash, 11,700 Btu/lb, and 0.60 lb S/MBtu.
- Clean coal (moisture-free): 4,384,000 ton/yr, 0.63% sulfur, 8.10% ash, 12,100 Btu/lb, and 0.52 lb S/MBtu.

TABLE B-19. PCC III PROCESS

TOTAL CAPITAL INVESTMENT

(Dense-medium cyclone, concentrating table)

Case variation - 2% S coal

	Investment, $
Direct Investment	
Coal receiving and storage	8,538,000
Raw coal sizing	2,317,000
Coarse coal cleaning	3,724,000
Fine coal cleaning	7,315,000
Refuse disposal as landfill	2,497,000
Clean coal storage	8,030,000
Total areas	32,421,000
Services, utilities, and miscellaneous	1,945,000
Total direct investment	34,366,000
Indirect Investment	
Engineering design and supervision	2,887,000
Architect and engineering contractor	687,000
Construction expense	4,090,000
Contractor fees	1,155,000
Total indirect investment	8,819,000
Contingency	6,478,000
Total fixed investment	49,663,000
Other Capital Charges	
Allowance for startup and modifications	4,966,000
Interest during construction	6,953,000
Total depreciable investment	61,582,000
Land	2,944,000
Working capital	8,899,000
Total capital investment	73,425,000
Dollars of total capital per kW of generating capacity	36.71

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.

Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.

Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-20. PCC III PROCESS

ANNUAL REVENUE REQUIREMENTS

(Dense-medium cyclone, concentrating table)

Case variation - 2% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	318,900 tons	31.58/ton	10,071,000
Total raw materials cost			10,071,000
Conversion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	22,600 kgal	0.13/kgal	3,000
Electricity	12,659,000 kWh	0.039/kWh	494,000
Diesel fuel	113,000 gal	0.70/gal	79,000
Process material: magnetite, Grade E	1,780 tons	93.31/ton	166,000
Maintenance, 6% of direct investment			2,062,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			4,866,000
Total direct costs			14,937,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,695,000
Average cost of capital and taxes at 8.6% of total capital investment			6,315,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			-
Total indirect costs			11,202,000
Gross annual revenue requirements			26,139,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			26,139,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	2.38	38.3

Basis
- Midwest location of coal-cleaning plant; time basis for scaling, mid-1982; plant life, 30 years; operating time, 6,000 hr/yr.
- Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $34,366,000; total depreciable investment, $61,582,000; total capital investment, $73,425,000.
- Raw coal (moisture-free): 4,384,000 ton/yr, 2% sulfur, 14.5% ash, 12,800 Btu/lb, and 1.56 lb S/MBtu.
- Clean coal (moisture-free): 3,787,000 ton/yr, 1.42% sulfur, 8.08% ash, 13,700 Btu/lb, and 1.03 lb S/MBtu.

TABLE B-21. PCC III PROCESS

TOTAL CAPITAL INVESTMENT

(Dense-medium cyclone, concentrating table)

	Case variation - 3.5% S coal
	Investment, $
Direct Investment	
Coal receiving and storage	8,609,000
Raw coal sizing	2,346,000
Coarse coal cleaning	3,768,000
Fine coal cleaning	7,450,000
Refuse disposal as landfill	2,497,000
Clean coal storage	8,112,000
Total areas	32,782,000
Services, utilities, and miscellaneous	1,967,000
Total direct investment	34,749,000
Indirect Investment	
Engineering design and supervision	2,919,000
Architect and engineering contractor	695,000
Construction expense	4,135,000
Contractor fees	1,168,000
Total indirect investment	8,917,000
Contingency	6,550,000
Total fixed investment	50,216,000
Other Capital Charges	
Allowance for startup and modifications	5,022,000
Interest during construction	7,030,000
Total depreciable investment	62,268,000
Land	2,944,000
Working capital	9,167,000
Total capital investment	74,379,000
Dollars of total capital per kW of generating capacity	37.19

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.

Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.

Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-22. PCC III PROCESS

ANNUAL REVENUE REQUIREMENTS

(Dense-medium cyclone, concentrating table)

Case variation - 3.5% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	363,400 tons	31.58/ton	11,476,000
Total raw materials cost			11,476,000
Conversion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	23,300 kgal	0.13/kgal	3,000
Electricity	12,849,000 kWh	0.039/kWh	501,000
Diesel fuel	114,000 gal	0.70/gal	80,000
Process material: magnetite, Grade E	1,820 tons	93.31/ton	170,000
Maintenance, 6% of direct investment			2,085,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			4,901,000
Total direct costs			16,377,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,736,000
Average cost of capital and taxes at 8.6% of total capital investment			6,397,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			-
Total indirect costs			11,325,000
Gross annual revenue requirements			27,702,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			27,702,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	2.52	25.3

Basis

Midwest location of coal-cleaning plant; time basis for scaling, mid-1982; plant life, 30 years; operating time, 6,000 hr/yr.

Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $34,749,000; total depreciable investment, $62,268,000; total capital investment, $74,379,000.

Raw coal (moisture-free): 4,494,000 ton/yr, 3.5% sulfur, 14.0% ash, 12,500 Btu/lb, and 2.8 lb S/MBtu.

Clean coal (moisture-free): 3,897,000 ton/yr, 2.63% sulfur, 8.51% ash, 13,300 Btu/lb, and 1.98 lb S/MBtu.

TABLE B-23. PCC III PROCESS

TOTAL CAPITAL INVESTMENT

(Dense-medium cyclone, concentrating table)

Base case - 5% S coal

	Investment, $
Direct Investment	
Coal receiving and storage	8,841,000
Raw coal sizing	2,438,000
Coarse coal cleaning	3,912,000
Fine coal cleaning	7,850,000
Refuse disposal as landfill	2,980,000
Clean coal storage	8,261,000
Total areas	34,282,000
Services, utilities, and miscellaneous	2,057,000
Total direct investment	36,339,000
Indirect Investment	
Engineering design and supervision	3,052,000
Architect and engineering contractor	727,000
Construction expense	4,324,000
Contractor fees	1,221,000
Total indirect investment	9,324,000
Contingency	6,849,000
Total fixed investment	52,512,000
Other Capital Charges	
Allowance for startup and modifications	5,251,000
Interest during construction	7,352,000
Total depreciable investment	65,115,000
Land	3,583,000
Working capital	10,007,000
Total capital investment	78,705,000
Dollars of total capital per kW of generating capacity	39.35

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.

Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-24. PCC III PROCESS

ANNUAL REVENUE REQUIREMENTS

(Dense-medium cyclone, concentrating table)

Base case - 5% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	471,800 tons	31.58/ton	14,889,000
Total raw materials cost			14,889,000
Conversion costs			
Operating labor and supervision	144,000 man-hr	13.80/man-hr	1,987,000
Utilities			
Process water	25,600 kgal	0.13/kgal	3,000
Electricity	13,459,000 kWh	0.039/kWh	525,000
Diesel fuel	138,000 gal	0.70/gal	97,000
Process material: magnetite, Grade E	1,970 tons	93.31/ton	184,000
Maintenance, 6% of direct investment			2,180,000
Analyses	4,000 man-hr	18.70/man-hr	75,000
Total conversion costs			5,051,000
Total direct costs			19,940,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			3,907,000
Average cost of capital and taxes at 8.6% of total capital investment			6,769,000
Overheads			
Plant, 50% of operating labor and supervision			993,000
Administrative, 10% of operating labor			199,000
Marketing, 10% of sales revenue			-
Total indirect costs			11,868,000
Gross annual revenue requirements			31,808,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			31,808,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	2.89	18.2

Basis

Midwest location of coal-cleaning plant; time basis for scaling, mid-1982; plant life, 30 years; operating time, 6,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $9,324,000; total depreciable investment, $65,115,000; total capital investment, $78,705,000.

Raw coal (moisture-free): 4,855,000 ton/yr, 5% sulfur, 16.7% ash, 12,000 Btu/lb, and 4.17 lb S/MBtu.

Clean coal (moisture-free): 4,111,000 ton/yr, 3.78% sulfur, 10.60% ash, 12,800 Btu/lb, and 2.94 lb S/MBtu.

TABLE B-25. KVB PROCESS

TOTAL CAPITAL INVESTMENT

Case variation - 0.7% S	Investment, $
Direct Investment	
Raw material handling and preparation	10,721,000
Sulfur oxidation	6,291,900
Reactor off-gas cleaning	11,448,200
Fine coal leaching	7,906,200
Coarse coal leaching	7,141,300
Product agglomeration and handling	12,212,100
Leach solution neutralization and water handling	6,250,300
Settling pond	3,962,500
Subtotal	65,933,500
Services, utilities, and miscellaneous	3,956,000
Total direct investment	69,889,500
Indirect Investment	
Engineering design and supervision	6,388,100
Architect and engineering contractor	1,568,300
Construction expense	8,494,200
Contractor fees	2,421,200
Total indirect investment	18,871,800
Contingency	17,752,300
Total fixed investment	106,513,600
Other Capital Charges	
Allowance for startup and modifications	10,651,400
Interest during construction	14,911,900
Total depreciable investment	132,076,900
Land	1,122,200
Working capital	15,710,900
Total capital investment	148,910,000
Dollars of total capital per kW of generating capacity	74.5

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-26. KVB PROCESS

ANNUAL REVENUE REQUIREMENTS

Case variation - 0.7% S

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	22,200 tons	43.31/ton	961,500
Oxygen	25,216 tons	21.13/ton	532,800
NO_2	952 tons	665.28/ton	633,300
NaOH (50%)	12,029 tons	99.57/ton	1,197,700
Sodium lignin sulfonate	81,200 tons	83.17/ton	6,753,400
Natural gas	24,000 kft^3	2.93/kft^3	70,300
Total raw materials cost			10,149,000
Conversion costs			
Operating labor and supervision	152,000 man-hr	13.80/man-hr	2,097,600
Utilities			
Steam	6,958,287 MBtu	2.54/MBtu	17,674,000
Process water	2,898,838 kgal	0.09/kgal	260,900
Electricity	242,458,453 kWh	0.039/kWh	9,455,900
Maintenance, 6% of direct investment			4,193,400
Analyses	24,000 man-hr	18.70/man-hr	448,800
Total conversion costs			34,130,600
Total direct costs			44,279,600
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			7,924,600
Average cost of capital and taxes at 8.6% of total capital investment			12,806,300
Overheads			
Plant, 50% of operating labor and supervision			1,048,800
Administrative, 10% of operating labor			209,800
Marketing, 10% of sales revenue			-
Total indirect costs			21,989,500
Gross annual revenue requirements			66,269,100
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			66,269,100

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirement	6.0	225.9

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000 MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $69,889,500; total depreciable investment, $132,076,900; and total capital investment, $148,267,400.

Raw coal (moisture-free): 4,454,694 tons/yr, 0.7% sulfur, 11.5% ash, 11,700 Btu/lb, and 0.6 lb S/MBtu.

Clean coal (moisture-free): 4,427,966 tons/yr, 0.37% sulfur, 11.2% ash, 11,800 Btu/lb, and 0.31 lb S/MBtu.

TABLE B-27. KVB PROCESS

TOTAL CAPITAL INVESTMENT

Case variation - 2.0% S	Investment $
Direct Investment	
Raw material handling and preparation	10,197,600
Sulfur oxidation	5,984,700
Reactor off-gas cleaning	10,389,300
Fine coal leaching	7,426,700
Coarse coal leaching	6,624,800
Product agglomeration and handling	11,328,800
Leach solution neutralization and water handling	5,913,200
Settling pond	8,321,400
Subtotal	66,686,500
Services, utilities, and miscellaneous	4,001,200
Total direct investment	70,687,700
Indirect Investment	
Engineering design and supervision	6,463,100
Architect and engineering contractor	1,568,600
Construction expense	8,476,900
Contractor fees	2,442,100
Total indirect investment	18,950,700
Contingency	17,927,700
Total fixed investment	107,566,100
Other Capital Charges	
Allowance for startup and modifications	10,756,600
Interest during construction	15,059,300
Total depreciable investment	133,382,000
Land	1,993,700
Working capital	16,652,400
Total capital investment	152,028,100
Dollars of total capital per kW of generating capacity	76.0

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-28. KVB PROCESS

ANNUAL REVENUE REQUIREMENTS

Case variation - 2.0% S

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	89,416 tons	43.31/ton	3,872,600
Oxygen	117,232 tons	21.13/ton	2,477,100
NO_2	952 tons	665.28/ton	633,300
NaOH (50%)	44,552 tons	99.57/ton	4,436,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,400
Natural gas	24,000 kft^3	2.93/kft^3	70,300
Total raw materials costs			17,743,700
Conversion costs			
Operating labor and supervision	152,000 man-hr	13.80/man-hr	2,097,600
Utilities			
Steam	5,352,009 MBtu	2.54/MBtu	13,594,100
Process water	2,663,074 kgal	0.09/kgal	239,700
Electricity	222,739,157 kWh	0.039/kWh	8,686,800
Maintenance, 6% of direct investment			4,241,300
Analyses	24,000 man-hr	18.70/man-hr	448,800
Total conversion costs			29,308,300
Total direct costs			47,052,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			8,002,900
Average cost of capital and taxes at 8.6% of total capital investment			13,074,400
Overheads			
Plant, 50% of operating labor and supervision			1,048,800
Administrative, 10% of operating labor			209,800
Marketing, 10% of sales revenue			-
Total indirect costs			22,335,900
Gross annual revenue requirements			69,387,900
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			69,387,900

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	6.3	57.9

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $70,687,700; total depreciable investment, $133,382,000; and total capital investment, $152,028,100.

Raw coal (moisture-free): 4,023,998 tons/yr, 2.0% sulfur, 14.5% ash, 13,000 Btu/lb, and 1.5 lb S/MBtu.

Clean coal (moisture-free): 3,899,254 tons/yr, 0.53% sulfur, 13.3% ash, 13,400 Btu/lb, and 0.40 lb S/MBtu

TABLE B-29. KVB PROCESS

TOTAL CAPITAL INVESTMENT

Case variation - 3.5% S	Investment, $
Direct Investment	
Raw material handling and preparation	10,197,600
Sulfur oxidation	5,984,700
Reactor off-gas cleaning	10,889,300
Fine coal leaching	7,426,700
Coarse coal leaching	6,624,800
Product agglomeration and handling	11,328,800
Leach solution neutralization and water handling	5,913,200
Settling pond	12,756,000
Subtotal	71,121,100
Services, utilities, and miscellaneous	4,267,300
Total direct investment	75,388,400
Indirect Investment	
Engineering design and supervision	6,567,200
Architect and engineering contractor	1,579,000
Construction expense	8,825,400
Contractor fees	2,564,600
Total indirect investment	19,536,200
Contingency	18,984,900
Total fixed investment	113,909,500
Other Capital Charges	
Allowance for startup and modifications	11,391,000
Interest during construction	15,947,300
Total depreciable investment	141,247,800
Land	2,881,200
Working capital	18,552,300
Total capital investment	162,681,300
Dollars of total capital per kW of generating capacity	81.3

Basis
- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.
- Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.
- Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-30. KVB PROCESS

ANNUAL REVENUE REQUIREMENTS

Case variation - 3.5% S

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	137,952 tons	43.31/ton	5,974,700
Oxygen	198,784 tons	21.13/ton	4,200,300
NO_2	952 tons	665.28/ton	633,300
NaOH (50%)	81,003 tons	99.57/ton	8,065,500
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,400
Natural gas	24,000 kft^3	2.93/ton	70,300
Total raw materials cost			25,198,500
Conversion costs			
Operating labor and supervision	152,000 man-hr	13.80/man-hr	2,097,600
Utilities			
Steam	5,350,723 MBtu	2.54/MBtu	13,590,800
Process water	2,663,074 kgal	0.09/kgal	239,700
Electricity	222,739,157 kWh	0.039/kWh	8,686,800
Maintenance, 6% of direct investment			4,523,300
Analyses	24,000 man-hr	18.70/man-hr	448,800
Total conversion costs			29,587,000
Total direct costs			54,785,500
Indirect Costs			
Capital charges			
Depreciation, interim replacement, and insurance at 6% of total depreciable investment			8,474,900
Average cost of capital and taxes at 8.6% of total capital investment			13,990,600
Overheads			
Plant, 50% of operating labor			1,048,800
Administrative, 10% of operating labor			209,800
Marketing, 10% of sales revenue			-
Total indirect costs			23,724,100
Gross annual revenue requirements			78,509,600
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			78,509,600

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	7.1	37.0

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000 MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $75,388,400; total depreciable investment, $141,247,800; and total capital investment, $162,681,300.

Raw coal (moisture-free): 4,148,437 ton/yr, 3.5% sulfur, 14.0% ash, 12,700 Btu/lb, and 2.8 lb S/MBtu.

Clean coal (moisture-free): 3,928,571 tons/yr, 1.00% sulfur, 11.9% ash, 13,300 Btu/lb, and 0.75 lb S/MBtu.

TABLE B-31. KVB PROCESS

TOTAL CAPITAL INVESTMENT

Base case -5% S coal	Investment, $
Direct Investment	
Raw material handling and preparation	10,197,600
Sulfur oxidation	5,984,700
Reactor off-gas cleaning	10,889,300
Fine coal leaching	7,426,700
Coarse coal leaching	6,624,800
Product agglomeration and handling	11,328,800
Leach solution neutralization and water handling	5,913,200
Settling pond	16,203,000
Subtotal	74,568,100
Services, utilities, and miscellaneous	4,474,100
Total direct investment	79,042,200
Indirect Investment	
Engineering design and supervision	6,639,900
Architect and engineering contractor	1,586,300
Construction expense	9,407,800
Contractor fees	2,658,500
Total indirect investment	20,292,500
Contingency	19,866,900
Total fixed investment	119,201,600
Other Capital Charges	
Allowance for startup and modifications	11,920,200
Interest during construction	16,688,200
Total depreciable investment	147,810,000
Land	3,611,000
Working capital	19,945,200
Total capital investment	171,366,200
Dollars of total capital per kW of generating capacity	85.7

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-32. KVB PROCESS

ANNUAL REVENUE REQUIREMENTS

Base case - 5% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	197,603 tons	43.31/ton	8,558,200
Oxygen	297,600 tons	21.13/ton	6,288,300
NO_2	952 tons	665.28/ton	633,300
NaOH (50%)	152,880 tons	99.57/ton	15,222,300
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,400
Natural gas	24,000 kft^3	2.93/kft^3	70,300
Total raw materials cost			37,026,800
Conversion costs			
Operating labor and supervision	152,000 man-hr	13.80/man-hr	2,097,600
Utilities			
Steam	5,349,838 MBtu	2.54/MBtu	13,588,600
Process water	2,663,074 kgal	0.09/kgal	239,700
Electricity	222,739,157 kWh	0.039/kWh	8,686,800
Maintenance, 6% of direct investment			4,742,500
Analysis	24,000 man-hr	18.70/man-hr	448,800
Total conversion costs			29,804,000
Total direct costs			66,830,800
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			8,868,600
Average cost of capital and taxes at 8.6% of total capital investment			14,737,500
Overheads			
Plant, 50% of operating labor and supervision			1,048,800
Administrative, 10% of operating labor and supervision			209,800
Marketing, 10% of sales revenue			-
Total indirect costs			24,864,700
Gross annual revenue requirements			91,695,500
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			91,695,500

	Mills/kWh	c/lb sulfur removed
Equivalent unit revenue requirements	8.3	27.4

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $79,042,200; total depreciable investment, $147,810,000; and total capital investment, $171,366,200.

Raw coal (moisture-free): 4,396,860 tons/yr, 5.0% sulfur, 16.7% ash, 12,000 Btu/lb, and 4.2 lb S/MBtu.

Clean coal (moisture-free): 4,050,388 tons/yr, 1.32% sulfur, 13.7% ash, 12,900 Btu/lb, and 1.02 lb S/MBtu.

TABLE B-33. TRW GRAVICHEM PROCESS

TOTAL CAPITAL INVESTMENT

Case variation - 0.7% S

	Investment, $
Direct Investment	
Raw material handling and preparation	7,874,600
Gravichem separation	8,309,600
Float coal washing	7,559,400
Reactor - regenerator	21,561,000
Acetone leaching	13,177,700
Acetone recovery and coal drying	29,606,100
Leach solution concentration	3,258,900
Neutralization and pond water handling	1,881,500
Product agglomeration and handling	13,062,800
Utility water handling	1,118,200
Settling pond	1,202,700
Subtotal	108,612,500
Services, utilities, and miscellaneous	6,516,800
Total direct investment	115,129,300
Indirect Investment	
Engineering design and supervision	5,512,800
Architect and engineering contractor	1,365,300
Construction expense	12,733,200
Contractor fees	3,538,100
Total indirect investment	23,149,400
Contingency	27,655,700
Total fixed investment	165,934,400
Other Capital Charges	
Allowance for startup and modifications	16,593,400
Interest during construction	23,230,800
Total depreciable investment	205,758,600
Land	587,000
Working capital	15,242,500
Total capital investment	221,059,800
Dollars of total capital per kW of generating capacity	110.5

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982, average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-34. TRW GRAVICHEM PROCESS

ANNUAL REVENUE REQUIREMENTS

Case variation - 0.7% S

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	9,602 tons	43.31/ton	415,900
Oxygen	4,513 tons	21.13/ton	95,400
Acetone	2,872 tons	471.24/ton	1,353,400
Copperas	2,257 tons	72.07/ton	162,700
Sulfuric acid	6,705 tons	45.18/ton	302,900
Total raw materials cost			2,330,300
Conversion costs			
Operating labor and supervision	160,000 man-hr	13.80/man-hr	2,208,000
Utilities			
Steam	8,044,368 MBtu	2.54/MBtu	20,432,700
Process water	15,736,259 kgal	0.07/kgal	1,101,500
Electricity	197,377,072 kWh	0.039/kWh	7,697,700
Maintenance, 6% of direct investment			6,907,800
Analyses	32,000 man-hr	18.70/man-hr	598,400
Total conversion costs			38,946,100
Total direct costs			41,276,400
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			12,345,500
Average cost of capital and taxes at 8.6% of total capital investment			19,011,100
Overheads			
Plant, 50% of operating labor and supervision			1,104,000
Administrative, 10% of operating labor			220,800
Marketing, 10% of sales revenue			9,900
Total indirect costs			32,691,300
Gross annual revenue requirements			73,967,700
Byproduct Sales Revenue			
Sulfur	2,865 long tons	53.00/long ton	(151,800)
Total annual revenue requirements			73,815,900

	Mills/kWh	c/lb sulfur removed
Equivalent unit revenue requirement	6.7	414.0

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.
- Clean coal production capacity for 2,000 MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $115,129,300; total depreciable investment, $205,758,600; and total capital investment, $221,059,800.
- Raw coal (moisture-free): 4,487,802 tons/yr, 0.7% sulfur, 11.5% ash, 11,700 Btu/lb, and 0.6 lb S/MBtu.
- Clean coal (moisture-free): 4,465,812 tons/yr, 0.50% sulfur, 11.3% ash, 11,700 Btu/lb, and 0.43 lb S/MBtu.

TABLE B-35. TRW GRAVICHEM PROCESS

TOTAL CAPITAL INVESTMENT

Case variation - 2.0% S

	Investment, $
Direct Investment	
Raw material handling and preparation	7,874,600
Gravichem separation	7,915,700
Float coal washing	7,201,100
Reactor - regenerator	20,539,000
Acetone leaching	12,553,100
Acetone recovery and coal drying	28,202,800
Leach solution concentration	3,104,400
Neutralization and pond water handling	1,792,300
Product agglomeration and handling	12,188,600
Utility water handling	1,065,200
Settling pond	4,149,800
Subtotal	106,586,600
Services, utilities, and miscellaneous	6,395,200
Total direct investment	112,981,800
Indirect Investment	
Engineering design and supervision	5,630,000
Architect and engineering contractor	1,376,400
Construction expense	12,682,400
Contractor fees	3,487,800
Total indirect investment	23,176,600
Contingency	27,231,700
Total fixed investment	163,390,100
Other Capital Charges	
Allowance for startup and modifications	16,339,000
Interest during construction	22,874,600
Total depreciable investment	202,603,700
Land	1,167,700
Working capital	14,930,000
Total capital investment	218,701,400
Dollars of total capital per kW of generating capacity	109.4

Basis
- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.
- Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.
- Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-36. TRW GRAVICHEM PROCESS

ANNUAL REVENUE REQUIREMENTS

Case variation - 2.0% S

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	48,992 tons	43.31/ton	2,121,800
Oxygen	23,016 tons	21.13/ton	486,300
Acetone	2,872 tons	471.24/ton	1,353,400
Copperas	11,508 tons	72.07/ton	829,400
Sulfuric acid	34,195 tons	45.18/ton	1,544,900
Total raw materials costs			6,335,800
Conversion costs			
Operating labor and supervision	160,000 man-hr	13.80/man-hr	2,208,000
Utilities			
Steam	7,313,062 MBtu	2.54/MBtu	18,575,200
Process water	14,512,600 kgal	0.07/kgal	1,015,900
Electricity	182,028,933 kWh	0.039/kWh	7,099,100
Maintenance, 6% of direct investment			6,778,900
Analyses	32,000 man-hr	18.70/man-hr	598,400
Total conversion costs			36,275,500
Total direct costs			42,611,300
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			12,156,200
Average cost of capital and taxes at 8.6% of total capital investment			18,808,300
Overheads			
Plant, 50% of operating labor and supervision			1,104,000
Administrative, 10% of operating labor			220,800
Marketing, 10% of sales revenue			50,800
Total indirect costs			32,340,100
Gross annual revenue requirements			74,951,400
Byproduct Sales Revenue			
Sulfur	16,054 long tons	53.00/long ton	(850,900)
Total annual revenue requirements			74,100,500

	Mills/kWh	c/lb sulfur removed
Equivalent unit revenue requirements	6.7	74.2

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $112,981,800; total depreciable investment, $202,603,700; and total capital investment, $218,701,400.

Raw coal (moisture-free): 4,037,586 tons/yr, 2.0% sulfur, 14.5% ash, 13,000 Btu/lb, and 1.5 lb S/MBtu.

Clean coal (moisture-free): 3,928,571 tons/yr, 0.78% sulfur, 13.4% ash, 13,300 Btu/lb, and 0.59 lb S/MBtu.

TABLE B-37. TRW GRAVICHEM PROCESS

TOTAL CAPITAL INVESTMENT

Case variation - 3.5% S

	Investment, $
Direct Investment	
Raw material handling and preparation	7,874,600
Gravichem separation	7,915,700
Float coal washing	7,201,100
Reactor - regenerator	20,539,000
Acetone leaching	12,553,100
Acetone recovery and coal drying	28,202,800
Leach solution concentration	3,104,400
Neutralization and pond water handling	1,792,300
Product agglomeration and handling	12,188,600
Utility water handling	1,065,200
Settling pond	6,096,700
Subtotal	108,533,500
Services, utilities, and miscellaneous	6,512,000
Total direct investment	115,045,500
Indirect Investment	
Engineering design and supervision	5,682,000
Architect and engineering contractor	1.382,200
Construction expense	12,852,600
Contractor fees	3,536,200
Total indirect investment	23,453,000
Contingency	27,699,700
Total fixed investment	166,198,200
Other Capital Charges	
Allowance for startup and modifications	16,619,800
Interest during construction	23,267,700
Total depreciable investment	206,085,700
Land	1,564,800
Working capital	15,482,900
Total capital investment	223,133,400
Dollars of total capital per kW of generating capacity	111.6

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-38. TRW GRAVICHEM PROCESS

ANNUAL REVENUE REQUIREMENTS

Case variation - 3.5% S

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	80,816 tons	43.31/ton	3,500,100
Oxygen	37,968 tons	21.13/ton	802,300
Acetone	2,872 tons	471.24/ton	1,353,400
Copperos	18,984 tons	72.07/ton	1,368,200
Sulfuric acid	56,408 tons	45.18/ton	2,548,500
Total raw materials cost			9,572,500
Conversion costs			
Operating labor and supervision	160,000 man-hr	13.80/man-hr	2,208,000
Utilities			
Steam	7,047,830 MBtu	2.54/MBtu	17,901,500
Process water	14,512,600 kgal	0.07/kgal	1,015,900
Electricity	182,028,933 kWh	0.039/kWh	7,099,100
Maintenance, 6% of direct investment			6,902,700
Analyses	32,000 man-hr	18.70/man-hr	598,400
Total conversion costs			35,725,600
Total direct costs			45,298,100
Indirect Costs			
Capital charges			
Depreciation, interim replacement, and insurance at 6% of total depreciable investment			12,365,100
Average cost of capital and taxes at 8.6% of total capital investment			19,189,500
Overheads			
Plant, 50% of operating labor and supervision			1,104,000
Administrative, 10% of operating labor			220,800
Marketing, 10% of sales revenue			83,600
Total indirect costs			32,963,000
Gross annual revenue requirements			78,261,100
Byproduct Sales Revenue			
Sulfur	28,022 long tons	53.00/long ton	(1,485,200)
Total annual revenue requirements			76,775,900

	Mills/kWh	c/lb sulfur removed
Equivalent unit revenue requirements	7.0	44.0

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $115,045,500; total depreciable investment, $206,085,700; and total capital investment, $223,133,400.

Raw coal (moisture-free): 4,126,651 tons/yr, 3.5% sulfur, 14.0% ash, 12,700 Btu/lb, and 2.8 lb S/MBtu.

Clean coal (moisture-free): 3,928,572 tons/yr, 1.47% sulfur, 11.9% ash, 13,300 Btu/lb, and 1.11 lb S/MBtu.

TABLE B-39. TRW GRAVICHEM PROCESS

TOTAL CAPITAL INVESTMENT

	Base case - 5% S coal
	Investment, $
Direct Investment	
Raw material handling and preparation	7,874,600
"Gravichem" separation	7,915,700
Float coal washing	7,201,100
Reactor - regenerator	20,539,000
Acetone leaching	12,553,100
Acetone recovery and coal drying	28,202,800
Leach solution concentration	3,104,400
Neutralization and pond water handling	1,792,300
Product agglomeration and handling	12,188,600
Utility water handling	1,065,200
Settling pond	8,219,500
Subtotal	110,656,300
Services, utilities, and miscellaneous	6,639,400
Total direct investment	117,295,700
Indirect Investment	
Engineering design and supervision	5,738,500
Architect and engineering contractor	1,387,900
Construction expense	13,028,600
Contractor fees	3,588,600
Total indirect investment	23,743,600
Contingency	28,207,900
Total fixed investment	169,247,200
Other Capital Charges	
Allowance for startup and modifications	16,924,700
Interest during construction	23,694,600
Total depreciable investment	209,866,500
Land	1,988,200
Working capital	16,194,400
Total capital investment	228,049,100
Dollars of total capital per kW of generating capacity	114.0

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-40. TRW GRAVICHEM PROCESS

ANNUAL REVENUE REQUIREMENTS

Base case - 5% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	119,200 tons	43.31/ton	5,162,600
Oxygen	56,000 tons	21.13/ton	1,183,500
Acetone	2,872 tons	471.24/ton	1,353,400
Copperas	28,000 tons	72.07/ton	2,018,000
Sulfuric acid	83,200 tons	45.18/ton	3,759,000
Total raw materials cost			13,476,500
Conversion costs			
Operating labor and supervision	160,000 man-hr	13.80/man-hr	2,208,000
Utilities			
Steam	6,728,550 MBtu	2.54/MBtu	17,090,500
Process water	14,512,600 kgal	0.07/kgal	1,015,900
Electricity	182,028,933 kWh	0.039/kWh	7,099,100
Maintenance, 6% of direct investment			7,037,700
Analysis	32,000 man-hr	18.70/man-hr	598,400
Total conversion costs			35,049,600
Total direct costs			48,526,100
Indirect Costs			
Capital charges			
Depreciation, interim replacement, and insurance at 6% of total depreciable investment			12,592,000
Average cost of capital and taxes at 8.6% of total capital investment			19,612,200
Overheads			
Plant, 50% of operating labor and supervision			1,104,000
Administrative, 10% of operating labor and supervision			220,800
Marketing, 10% of sales revenue			123,500
Total indirect costs			33,652,500
Gross annual revenue requirements			82,178,600
Byproduct Sales Revenue			
Sulfur	45,411 long tons	53.00/long ton	(2,406,800)
Total annual revenue requirements			79,771,800

	Mills/kWh	c/lb sulfur removed
Equivalent unit revenue requirements	7.3	27.4

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,550 Btu/kWh and 5,500 hr/yr.

Total direct investment, $117,295,700; total depreciable investment, $209,866,500; and total capital investment, $228,049,100.

Raw coal (moisture-free): 4,364,642 tons/yr, 5.0% sulfur, 16.7% ash, 12,000 Btu/lb, and 4.2 lb S/MBtu.

Clean coal (moisture-free): 4,050,389 tons/yr, 1.95% sulfur, 13.6% ash, 12,900 Btu/lb, and 1.51 lb S/MBtu.

TABLE B-41. KENNECOTT PROCESS

TOTAL CAPITAL INVESTMENT

Case variation - 0.7% S

	Investment, $
Direct Investment	
Raw materials handling and preparation	14,549,700
Reactor area	52,321,600
Coal filtration area	25,713,500
Product agglomeration and handling	30,376,700
Neutralization and water handling	6,459,400
Settling pond	2,186,400
Subtotal	131,609,300
Services, utilities, and miscellaneous	7,896,400
Total direct investment	139,503,700
Indirect Investment	
Engineering design and supervision	3,461,400
Architect and engineering contractor	846,100
Construction expense	15,116,800
Contractor fees	4,094,100
Total indirect investment	23,518,400
Contingency	32,604,400
Total fixed investment	195,626,500
Other Capital Charges	
Allowance for startup and modifications	19,562,700
Interest during construction	27,387,700
Total depreciable investment	242,576,900
Land	611,600
Working capital	26,035,800
Total capital investment	269,224,300
Dollars total capital per kW of generating capacity	134.6

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-42. KENNECOTT PROCESS

ANNUAL REVENUE REQUIREMENTS

Case variation - 0.7% S

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	22,899 tons	43.31/ton	991,800
Oxygen	556,658 tons	21.13/ton	11,762,200
Sodium lignin sulfonate	174,421 tons	83.17/ton	14,506,600
Total raw materials costs			27,260,600
Conversion costs			
Operating labor and supervision	168,000 man-hr	13.80/man-hr	2,318,400
Utilities			
Process Btu loss	1,666,029 MBtu	1.36/MBtu	2,265,800
Steam	13,704,284 tons	2.54/MBtu	34,808,900
Process water	9,440,960 kgal	0.07/kgal	660,900
Electricity	713,048,746 kWh	0.039/kWh	27,808,900
Maintenance, 6% of direct investment			8,370,200
Analyses	32,000 man-hr	18.70/man-hr	598,400
Total conversion costs			76,831,500
Total direct costs			104,092,100
Indirect Costs			
Capital charges			
Depreciation, interim replacement, and insurance at 6% of total depreciable investment			14,554,600
Average cost of capital and taxes at 8.6% of total capital investment			23,153,300
Overheads			
Plant, 50% of operating labor and supervision			1,159,200
Administrative, 10% of operating labor			231,800
Marketing, 10% of sales revenue			-
Total indirect costs			39,098,900
Gross annual revenue requirements			143,191,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			143,191,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	13.0	619.6

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000 MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $139,503,700; total depreciable investment, $242,576,900; and total capital investment, $269,224,300.

Raw coal (moisture-free): 4,706,190 tons/yr, 0.7% sulfur, 11.5% ash, 11,700 Btu/lb, and 0.6 lb S/MBtu.

Clean coal (moisture-free): 4,837,963 tons/yr, 0.45% sulfur, 11.1% ash, 10,800 Btu/lb, and 0.42 lb S/MBtu.

TABLE B-43. KENNECOTT PROCESS

TOTAL CAPITAL INVESTMENT

Case variation - 2.0% S

	Investment, $
Direct Investment	
Raw materials handling and preparation	13,856,900
Reactor area	48,820,200
Coal filtration area	24,489,000
Product agglomeration and handling	28,343,900
Neutralization and water handling	6,151,800
Settling pond	4,489,800
Subtotal	126,151,600
Services, utilities, and miscellaneous	7,569,100
Total direct investment	133,720,700
Indirect Investment	
Engineering design and supervision	3,541,000
Architect and engineering contractor	854,100
Construction expense	14,589,700
Contractor fees	3,964,400
Total indirect investment	22,949,200
Contingency	31,334,000
Total fixed investment	188,003,900
Other Capital Charges	
Allowance for startup and modifications	18,800,400
Interest during construction	26,320,500
Total depreciable investment	233,124,800
Land	1,237,000
Working capital	24,833,600
Total capital investment	259,195,400
Dollars of total capital per kW of generating capacity	129.6

Basis
Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.
Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.
Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-44. KENNECOTT PROCESS

ANNUAL REVENUE REQUIREMENTS

Case variation - 2.0% S

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	118,495 tons	43.31/ton	5,132,000
Oxygen	600,520 tons	21.13/ton	12,689,000
Sodium lignin sulfonate	155,985 tons	83.17/ton	12,973,300
Total raw materials cost			30,794,300
Conversion costs			
Operating labor and supension	168,000 man-hr	13.80/man-hr	2,318,400
Utilities			
Process Btu loss	1,655,224 MBtu	1.36/MBtu	2,251,100
Steam	12,458,440 MBtu	2.54/MBtu	31,644,400
Process water	8,741,630 kgal	0.07/kgal	611,900
Electricity	660,230,321 kWh	0.039/kWh	25,749,000
Maintenance, 6% of direct investment			8,023,200
Analyses	32,000 man-hr	18.70/man-hr	598,400
Total conversion costs			71,196,400
Total direct costs			101,990,700
Indirect Costs			
Capital charges			
Depreciation, interim replacement, and insurance at 6% of total depreciable investment			13,987,500
Average cost of capital and taxes at 8.6% of total capital investment			22,290,800
Overheads			
Plant, 50% of operating labor			1,159,200
Administrative, 10% of operating labor			231,800
Marketing, 10% of sales revenue			-
Total indirect costs			37,669,300
Gross annual revenue requirements			139,660,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			139,660,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirement	12.7	132.2

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.
- Clean-coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $133,720,700; total depreciable investment, $233,124,800; and total capital investment, $259,195,400.
- Raw coal (moisture-free): 4,208,754 tons/yr, 2.0% sulfur, 14.5% ash, 13,000 Btu/lb, and 1.5 lb S/MBtu.
- Clean coal (moisture-free): 4,318,182 tons/yr, 0.73% sulfur, 13.8% ash, 12,100 Btu/lb, and 0.60 lb S/MBtu.

TABLE B-45. KENNECOTT PROCESS

TOTAL CAPITAL INVESTMENT

Case variation - 3.5% S

	Investment, $
Direct Investment	
Raw materials handling and preparation	13,856,900
Reactor area	48,820,200
Coal filtration area	24,489,000
Product agglomeration and handling	28,343,900
Neutralization and water handling	6,151,800
Settling pond	8,884,200
Subtotal	130,546,000
Services, utilities, and miscellaneous	7,832,800
Total direct investment	138,378,800
Indirect Investment	
Engineering design and supervision	3,661,500
Architect and engineering contractor	866,100
Construction expense	14,958,200
Contractor fees	4,069,000
Total indirect investment	23,554,800
Contingency	32,386,700
Total fixed investment	194,320,300
Other Capital Charges	
Allowance for startup and modifications	19,432,000
Interest during construction	27,204,800
Total depreciable investment	240,957,100
Land	2,107,800
Working capital	25,276,300
Total capital investment	268,341,200
Dollars of total capital per kW of generating capacity	134.2

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-46. KENNECOTT PROCESS

ANNUAL REVENUE REQUIREMENTS

Case variation - 3.5% S

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	207,360 tons	43.31/ton	8,980,800
Oxygen	706,886 tons	21.13/ton	14,936,500
Sodium lignin sulfonate	160,326 tons	83.17/ton	13,334,300
Total raw materials costs			37,251,600
Conversion costs			
Operating labor and supervision	168,000 man-hr	13.80/man-hr	2,318,400
Utilities			
Process Btu loss	1,662,240 MBtu	1.36/MBtu	2,260,600
Steam	12,458,440 MBtu	2.54/MBtu	31,644,400
Process water	8,741,630 kgal	0.07/kgal	611,900
Electricity	660,230,321 kWh	0.039/kWh	25,749,000
Maintenance, 6% of direct investment			8,302,700
Analyses	32,000 man-hr	18.70/man-hr	598,400
Total conversion costs			71,485,400
Total direct costs			108,737,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance at 6% of total depreciable investment			14,457,400
Average cost of capital and taxes at 8.6% of total capital investment			23,077,300
Overheads			
Plant, 50% of operating labor and supervision			1,159,200
Administrative, 10% of operating labor			231,800
Marketing, 10% of sales revenue			-
Total indirect costs			38,925,700
Gross annual revenue requirements			147,662,700
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			147,662,700

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	13.4	87.2

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $138,378,800; total depreciable investment, $240,957,100; and total capital investment, $268,341,200.

Raw coal (moisture-free): 4,325,868 tons/yr, 3.5% sulfur, 14.0% ash, 12,700 Btu/lb, and 2.8 lb S/MBtu.

Clean coal (moisture-free): 4,390,756 tons/yr, 1.34% sulfur, 13.2% ash, 11,900 Btu/lb, and 1.13 lb S/MBtu.

TABLE B-47. KENNECOTT PROCESS

TOTAL CAPITAL INVESTMENT

Base case - 5% S coal

	Investment, $
Direct Investment	
Raw materials handling and preparation	13,856,900
Reactor area	48,820,200
Coal filtration area	24,489,000
Product agglomeration and handling	28,343,900
Neutralization and water handling	6,151,800
Settling pond	13,961,900
Subtotal	135,623,700
Services, utilities, and miscellaneous	8,137,400
Total direct investment	143,761,100
Indirect Investment	
Engineering design and supervision	3,777,600
Architect and engineering contractor	877,700
Construction expense	15,321,300
Contractor fees	4,188,700
Total indirect investment	24,165,300
Contingency	33,585,300
Total fixed investment	201,511,700
Other Capital Charges	
Allowance for startup and modifications	20,151,200
Interest during construction	28,211,600
Total depreciable investment	249,874,500
Land	3,152,600
Working capital	29,188,800
Total capital investment	281,215,900
Dollars of total capital per kW of generating capacity	140.6

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time 8,000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-48. KENNECOTT PROCESS

ANNUAL REVENUE REQUIREMENTS

Base case - 5% S coal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	329,915 tons	43.31/ton	14,228,600
Oxygen	868,504 tons	21.13/ton	18,351,500
Sodium lignin sulfonate	171,200 tons	83.17/ton	14,238,700
Total raw materials cost			46,878,800
Conversion costs			
Operating labor and supervision	168,000 man-hr	13.80/man-hr	2,318,400
Process Btu loss	2,005,900 MBtu	1.36/MBtu	2,728,000
Steam	12,458,440 MBtu	2.54/MBtu	31,644,400
Process water	8,741,630 kgal	0.07/kgal	611,900
Electricity	660,230,321 kWh	0.039/kWh	25,749,000
Maintenance, 6% of direct investment			8,625,700
Analysis	32,000 man-hr	18.70/man-hr	598,400
Total conversion costs			72,275,800
Total direct costs			119,154,600
Indirect Costs			
Capital charges			
Depreciation, interim replacement, and insurance at 6% of total depreciable investment			14,992,500
Average cost of capital and taxes at 8.6% of total capital investment			24,184,600
Overheads			
Plant, 50% of operating labor and supervision			1,159,200
Administrative, 10% of operating labor and supervision			231,800
Marketing, 10% of sales revenue			-
Total indirect costs			40,568,100
Gross annual revenue requirements			159,722,700
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			159,722,700

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	14.7	53.8

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $143,761,100; total depreciable investment, $249,874,500; and total capital investment, $281,215,900.

Raw coal (moisture-free): 4,619,275 tons/yr, 5.0% sulfur, 16.7% ash, 12,000 Btu/lb, and 4.2 lb S/MBtu.

Clean coal (moisture-free): 4,623,894 tons/yr, 1.81% sulfur, 15.8% ash, 11,300 Btu/lb, and 1.60 lb S/MBtu.

TABLE B-49. COMBINATION PCC-KVB PROCESS

TOTAL CAPITAL INVESTMENT

	0.7% sulfur
	Investment, $
Direct Investment	
Coal receiving and storage	8,799,000
Raw coal sizing	1,616,000
Coarse coal cleaning	1,575,000
Intermediate coal cleaning	2,234,000
Fine coal cleaning	2,696,000
Refuse disposal as landfill	1,904,000
Interim storage area	4,513,000
Raw material handling and preparation	6,208,000
Sulfur oxidation	6,292,000
Reactor off-gas cleaning	11,448,000
Fine coal leaching	7,906,000
Coarse coal leaching	7,142,000
Product agglomeration and handling	12,212,000
Leach solution neutralization and water handling	6,250,000
Settling pond	3,963,000
Subtotal	84,758,000
Services, utilities, and miscellaneous	5,593,000
Total direct investment	90,351,000
Indirect Investment	
Engineering design and supervision	8,817,000
Architect and engineering contractor	2,146,000
Construction expense	11,936,000
Contractor fees	3,393,000
Total indirect investment	26,292,000
Contingency	23,203,000
Total fixed investment	139,846,000
Other Capital Charges	
Allowance for startup and modifications	14,831,000
Interest during construction	20,763,000
Total depreciable investment	175,440,000
Land	3,296,000
Working capital	19,007,000
Total capital investment	197,743,000
Dollars of total capital per kW equivalent of clean coal	98.9

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond and landfill sites for sludge and refuse disposal located 1 mile from coal preparation plant.

TABLE B-50. COMBINATION PCC-KVB PROCESS

ANNUAL REVENUE REQUIREMENTS

0.7% sulfur

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	22,200 tons	43.31/ton	962,000
Oxygen	25,216 tons	21.13/ton	533,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	35,424 tons	99.57/ton	3,527,000
Sodium lignin sulfonate	81,200 tons	83.17/ton	6,753,000
Natural gas	24,000 kft^3	2.93/kft^3	71,000
Coal loss (Btu basis)	283,400 tons	31.58/ton	8,949,000
Total raw materials cost			21,428,000
Conversion costs			
Operating labor and supervision	296,000 man-hr	13.80/man-hr	4,085,000
Utilities			
Diesel fuel	97,000 gal	0.70/gal	68,000
Steam	6,958,287 MBtu	2.54/MBtu	17,674,000
Process water	2,946,438 kgal	0.09/kgal	265,000
Electricity	257,358,453 kWh	0.039/kWh	10,037,000
Process material: magnetite	2,720 tons	93.31/ton	254,000
Maintenance, 6% of direct investment			5,928,000
Analyses	28,000 man-hr	18.70/man-hr	524,000
Total conversion costs			38,835,000
Total direct costs			60,263,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements and insurance at 6% of total depreciable investment			11,034,000
Average cost of capital and taxes at 8.6% of total capital investment			18,369,000
Overheads			
Plant, 50% of operating labor and supervision			2,042,000
Administrative, 10% of operating labor and supervision			409,000
Marketing, 10% of sales revenue			-
Total indirect costs			31,854,000
Gross annual revenue requirements			92,117,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			92,117,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	8.4	258.0

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, PCC-6000 hr/yr, KVB-8000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $90,351,000; total depreciable investment, $175,440,000; and total capital investment, $197,743,000.

Raw coal (moisture-free): 4,683,536 tons/yr, 0.7% sulfur, 11.5% ash, 11,700 Btu/lb, and 0.6 lb S/MBtu.

Clean coal (moisture-free): 4,247,967 tons/yr, 0.36% sulfur, 7.7% ash, 12,300 Btu/lb, and 0.29 lb S/MBtu.

TABLE B-51. COMBINATION PCC-KVB PROCESS

TOTAL CAPITAL INVESTMENT

	2% sulfur
	Investment, $
Direct Investment	
Coal receiving and storage	8,529,000
Raw coal sizing	1,543,000
Coarse coal cleaning	1,512,000
Intermediate coal cleaning	2,132,000
Fine coal cleaning	2,573,000
Refuse disposal as landfill	2,558,000
Interim storage area	4,513,000
Raw material handling and preparation	5,685,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Settling pond	8,321,000
Subtotal	85,534,000
Services, utilities, and miscellaneous	5,614,000
Total direct investment	91,148,000
Indirect Investment	
Engineering design and supervision	8,856,000
Architect and engineering contractor	2,139,000
Construction expense	11,867,000
Contractor fees	3,399,000
Total indirect investment	26,261,000
Contingency	23,297,000
Total fixed investment	140,706,000
Other Capital Charges	
Allowance for startup and modifications	14,474,000
Interest during construction	20,823,000
Total depreciable investment	176,003,000
Land	5,002,000
Working capital	25,481,000
Total capital investment	201,484,000
Dollars of total capital per kW equivalent of clean coal	100.7

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond and landfill sites for sludge and refuse disposal located 1 mile from coal preparation plant.

TABLE B-52. COMBINATION PCC-KVB PROCESS

ANNUAL REVENUE REQUIREMENTS

	2% sulfur		
	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	89,416 tons	43.31/ton	3,873,000
Oxygen	117,232 tons	21.13/ton	2,477,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	70,224 tons	99.57/ton	6,992,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 kft^3	2.93/kft^3	70,000
Coal loss (Btu basis)	315,600 tons	31.58/ton	9,966,000
Total raw materials cost			30,265,000
Conversion costs			
Operating labor and supervision	296,000 man-hr	13.80/man-hr	4,085,000
Utilities			
Diesel fuel	119,000 gal	0.70/gal	83,000
Steam	5,352,009 MBtu	2.54/MBtu	13,594,000
Process water	2,702,674 kgal	0.09/kgal	243,000
Electricity	236,847,157 kWh	0.039/kWh	9,237,000
Process material: magnetite	2,490 tons	93.31/ton	232,000
Maintenance, 6% of direct investment			5,950,000
Analyses	28,000 man-hr	18.70/man-hr	524,000
Total conversion costs			33,948,000
Total direct costs			64,213,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements and insurance at 6% of total depreciable investment			11,066,000
Average cost of capital and taxes at 8.6% of total capital investment			18,482,000
Overheads			
Plant, 50% of operating labor and supervision			2,042,000
Administrative, 10% of operating labor and supervision			409,000
Marketing, 10% of sales revenue			-
Total indirect costs			31,999,000
Gross annual revenue requirements			96,212,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			96,212,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	8.8	71.4

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, PCC-6000 hr/yr, KVB-8000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $91,148,000 total depreciable investment, $176,003,000; and total capital investment, $201,484,000.

Raw coal (moisture-free): 4,354,530 tons/yr, 2% sulfur, 14.5% ash, 13,000 Btu/lb, and 1.54 lb S/MBtu.

Clean coal (moisture-free): 3,679,577 tons/yr, 0.53% sulfur, 6.8% ash, 14,200 Btu/lb, and 0.37 lb S/MBtu.

TABLE B-53. COMBINATION PCC-KVB PROCESS

TOTAL CAPITAL INVESTMENT

	3.5% sulfur
	Investment, $
Direct Investment	
Coal receiving and storage	8,608,000
Raw coal sizing	1,564,000
Coarse coal cleaning	1,547,000
Intermediate coal cleaning	2,162,000
Fine coal cleaning	2,594,000
Refuse disposal as landfill	2,581,000
Interim storage area	4,513,000
Raw material handling and preparation	5,685,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Settling pond	12,756,000
Subtotal	90,178,000
Services, utilities, and miscellaneous	5,893,000
Total direct investment	96,071,000
Indirect Investment	
Engineering design and supervision	8,980,000
Architect and engineering contractor	2,154,000
Construction expense	12,244,000
Contractor fees	3,530,000
Total indirect investment	26,908,000
Contingency	24,400,000
Total fixed investment	147,379,000
Other Capital Charges	
Allowance for startup and modifications	15,543,000
Interest during construction	21,759,000
Total depreciable investment	184,681,000
Land	5,915,000
Working capital	27,662,000
Total capital investment	212,343,000
Dollars of total capital per kW equivalent of clean coal	106.2

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond and landfill sites for sludge and refuse disposal located 1 mile from coal preparation plant.

TABLE B-54. COMBINATION PCC-KVB PROCESS

ANNUAL REVENUE REQUIREMENTS

	3.5% sulfur		
	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	137,952 tons	43.31/ton	5,975,000
Oxygen	198,784 tons	21.13/ton	4,200,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	128,576 tons	99.57/ton	12,802,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 kft^3	2.93/kft^3	70,000
Coal loss (Btu basis)	368,650 tons	31.58/ton	11,642,000
Total raw materials cost			41,576,000
Conversion costs			
Operating labor and supervision	296,000 man-hr	13.80/man-hr	4,085,000
Utilities			
Diesel fuel	121,000 gal	0.70/gal	85,000
Steam	5,350,723 MBtu	2.54/MBtu	13,591,000
Process water	2,702,674 kgal	0.09/kgal	243,000
Electricity	237,076,157 kWh	0.039/kWh	9,246,000
Process material: magnetite	2,550 tons	93.31/ton	238,000
Maintenance, 6% of direct investment			6,246,000
Analyses	28,000 man-hr	18.70/man-hr	524,000
Total conversion costs			34,258,000
Total direct costs			75,834,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements and insurance at 6% of total depreciable investment			11,563,000
Average cost of capital and taxes at 8.6% of total capital investment			19,463,000
Overheads			
Plant, 50% of operating labor and supervision			2,042,000
Administrative, 10% of operating labor and supervision			409,000
Marketing, 10% of sales revenue			-
Total indirect costs			33,477,000
Gross annual revenue requirements			109,311,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			109,311,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirements	9.9	45.4

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, PCC-6000 hr/yr, KVB-8000 hr/yr.
- Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 B /kWh and 5,500 hr/yr.
- Total direct investment, $96,071,000; total depreciable investment, $184,681,000; and total capital investment, $212,343,000.
- Raw coal (moisture-free): 4,486,288 tons/yr, 3.5% sulfur, 14.0% ash, 12,700 Btu/lb, and 2.75 lb S/MBtu.
- Clean coal (moisture-free): 3,705,674 tons/yr, 0.98% sulfur, 6.7% ash, 14,100 Btu/lb, and 0.70 lb S/MBtu.

TABLE B-55. COMBINATION PCC-KVB PROCESS

TOTAL CAPITAL INVESTMENT

	5% sulfur
	Investment, $
Direct Investment	
Coal receiving and storage	8,841,000
Raw coal sizing	1,627,000
Coarse coal cleaning	1,585,000
Intermediate coal cleaning	2,249,000
Fine coal cleaning	2,696,000
Refuse disposal as landfill	3,058,000
Interim storage area	4,513,000
Raw material handling and preparation	5,685,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Settling pond	16,203,000
Subtotal	94,625,000
Services, utilities, and miscellaneous	6,173,000
Total direct investment	100,798,000
Indirect Investment	
Engineering design and supervision	9,161,000
Architect and engineering contractor	2,186,000
Construction expense	12,980,000
Contractor fees	3,668,000
Total indirect investment	27,995,000
Contingency	25,525,000
Total fixed investment	154,318,000
Other Capital Charges	
Allowance for startup and modifications	16,257,000
Interest during construction	22,761,000
Total depreciable investment	193,336,000
Land	7,297,000
Working capital	28,791,000
Total capital investment	229,424,000
Dollars of total capital per kW equivalent of clean coal	114.7

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond and landfill sites for sludge and refuse disposal located 1 mile from coal preparation plant.

TABLE B-56. COMBINATION PCC-KVB PROCESS

ANNUAL REVENUE REQUIREMENTS

	5% sulfur		
	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Lime	197,603 tons	43.31/ton	8,558,000
Oxygen	297,600 tons	21.13/ton	6,288,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	152,880 tons	99.57/ton	15,222,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 tons	2.93/kft^3	70,000
Coal loss (Btu basis)	478,000 tons	31.58/ton	15,098,000
Total raw materials cost			52,123,000
Conversion costs			
Operating labor and supervision	296,000 man-hr	13.80/man-hr	4,085,000
Utilities			
Diesel fuel	145,000 gal	0.70/gal	102,000
Steam	5,349,838 MBtu	2.54/MBtu	13,588,000
Process water	2,708,374 kgal	0.09/kgal	244,000
Electricity	237,849,157 kWh	0.039/kWh	9,276,000
Process material: magnetite	2,760 tons	93.31/ton	257,000
Maintenance, 6% of direct investment			6,545,000
Analyses	28,000 man-hr	18.70/man-hr	524,000
Total conversion costs			34,621,000
Total direct costs			86,744,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements and insurance at 6% of total depreciable investment			12,096,000
Average cost of capital and taxes at 8.6% of total capital investment			20,536,000
Overheads			
Plant, 50% of operating labor and supervision			2,042,000
Administrative, 10% of operating labor and supervision			409,000
Marketing, 10% of sales revenue			-
Total indirect costs			35,083,000
Gross annual revenue requirements			121,827,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			121,827,000

	Mills/kWh	c/lb sulfur removed
Equivalent unit revenue requirements	11.0	31.5

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, PCC-6000 hr/yr, KVB-8000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investmnet, $100,798,000; total depreciable investment, $193,336,000; and total capital investment, $229,424,000.

Raw coal (moisture-free): 4,796,394 tons/yr, 5% sulfur, 16.7% ash. 12,000 Btu/lb, and 4.17 lb S/MBtu.

Clean coal (moisture-free): 3,841,912 tons/yr, 1.26% sulfur, 8.0 ash, 13,600 Btu/lb, and 0.93 lb S/MBtu.

TABLE B-57. PCC I PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

2% S - 1.2 lb SO_2/MBtu

	Investment, $
Direct Investment	
Raw material handling and preparation	12,104,000
Raw coal sizing	1,543,000
Coarse coal cleaning	1,512,000
Intermediate coal cleaning	2,132,000
Fine coal cleaning	2,573,000
Clean coal storage	8,028,000
Scrubbing	28,281,000
Waste disposal	9,602,000
Total areas	65,775,000
Services, utilities, and miscellaneous	3,947,000
Total direct investment	69,722,000
Indirect Investment	
Engineering design and supervision	5,857,000
Architect and engineering contractor	1,395,000
Construction expense	8,297,000
Contractor fees	2,342,000
Total indirect investment	17,891,000
Contingency	15,733,000
Total fixed investment	103,346,000
Other Capital Charges	
Allowance for startup and modifications	10,335,000
Interest during construction	14,469,000
Total depreciable investment	128,150,000
Land	4,100,000
Working capital	10,487,000
Total capital investment	142,737,000
Dollars of total capital per kW of generating capacity	71.37

Basis
- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.
- Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.
- Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-58. PCC I PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

2% S - 1.2 lb SO_2/MBtu

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	315,600 tons	31.58/ton	9,966,000
Limestone	83,100 tons	7.75/ton	644,000
Total raw materials cost			10,610,000
Conversion costs			
Operating labor and supervision	168,700 man-hr	13.80/man-hr	2,328,000
Utilities			
Process water	344,000 kgal	0.13/kgal	45,000
Electricity	75,470,000 kWh	0.039/kWh	2,943,000
Diesel fuel	119,000 gal	0.70/gal	83,000
Steam	879,800 klb	2.35/klb	2,068,000
Process material: magnetite, Grade E	2,490 tons	93.31/ton	232,000
Maintenance			4,183,000
Analyses	7,600 man-hr	18.70/man-hr	142,000
Total conversion costs			12,024,000
Total direct costs			22,634,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			7,689,000
Average cost of capital and taxes			12,275,000
Overheads			
Plant			2,434,000
Administrative			233,000
Marketing			-
Total indirect costs			22,631,000
Gross annual revenue requirements			45,265,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			45,265,000

	Mills/kWh	¢/lb S removed
Equivalent unit revenue requirements	4.12	40.49

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 yr; operating time, 6,000 hr/yr.
- Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $69,722,000; total depreciable investment, $128,150,000; and total capital investment, $142,737,000.
- Raw coal (moisture-free): 4,362,000 tons/yr, 2% S, 14.5% ash, 12,800 Btu/lb, and 1.56 lb S/MBtu.
- Clean coal (moisture-free): 3,749,000 tons/yr, 1.36% S, 7.45% ash, 14,000 Btu/lb, and 0.97 lb S/MBtu.

TABLE B-59. PCC I PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

3.5% S - 1.2 lb SO_2/MBtu

	Investment, $
Direct Investment	
Raw material handling and preparation	15,073,000
Raw coal sizing	1,564,000
Coarse coal cleaning	1,547,000
Intermediate coal cleaning	2,162,000
Fine coal cleaning	2,594,000
Clean coal storage	8,048,000
Scrubbing	43,681,000
Waste disposal	20,061,000
Total areas	94,730,000
Services, utilities, and miscellaneous	5,684,000
Total direct investment	100,414,000
Indirect Investment	
Engineering design and supervision	8,434,000
Architect and engineering contractor	2,009,000
Construction expense	11,949,000
Contractor fees	3,374,000
Total indirect investment	25,766,000
Contingency	23,431,000
Total fixed investment	149,611,000
Other Capital Charges	
Allowance for startup and modifications	14,961,000
Interest during construction	20,945,000
Total depreciable investment	185,517,000
Land	5,922,000
Working capital	12,051,000
Total capital investment	203,490,000
Dollars of total capital per kW of generating capacity	101.74

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.

Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-60. PCC I PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

3.5% S - 1.2 lb SO_2/MBtu

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	368,650 tons	31.58/ton	11,642,000
Limestone	315,900 tons	7.75/ton	2,448,000
Total raw materials cost			14,090,000
Conversion costs			
Operating labor and supervision	180,000 man-hr	13.80/man-hr	2,484,000
Utilities			
Process water	726,000 kgal	0.11/kgal	80,000
Electricity	133,000,000 kWh	0.039/kWh	5,187,000
Diesel fuel	121,000 gal	0.70/kgal	85,000
Steam	1,662,100 klb	2.35/klb	3,906,000
Process material: magnetite, Grade E	2,550 tons	93.31/ton	238,000
Maintenance			6,024,000
Analyses	9,300 man-hr	18.70/man-hr	174,000
Total conversion costs			18,178,000
Total direct costs			32,268,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			11,131,000
Average cost of capital and taxes			17,500,000
Overheads			
Plant			3,441,000
Administrative			249,000
Marketing			-
Total indirect costs			32,321,000
Gross annual revenue requirements			64,589,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			64,589,000

	Mills/kWh	c/lb S removed
Equivalent unit revenue requirements	5.87	25.74

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 yr; operating time, 6,000 hr/yr.
- Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $100,414,000; total depreciable investment, $185,517,000; and total capital investment, $203,490,000.
- Raw coal (moisture-free): 4,480,000 tons/yr, 3.5% S, 14.0% ash, 12,500 Btu/lb, and 2.79 lb S/MBtu.
- Clean coal (moisture-free): 3,862,000 tons/yr, 2.55% S, 7.99% ash, 13,400 Btu/lb, and 1.91 lb S/MBtu.

TABLE B-61. PCC I PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

5% S - 1.2 lb SO_2/MBtu

	Investment, $
Direct Investment	
Raw material handling and preparation	17,612,000
Raw coal sizing	1,627,000
Coarse coal cleaning	1,585,000
Intermediate coal cleaning	2,249,000
Fine coal cleaning	2,696,000
Clean coal storage	8,261,000
Scrubbing	51,033,000
Waste disposal	29,840,000
Total areas	114,903,000
Services, utilities, and miscellaneous	6,894,000
Total direct investment	121,797,000
Indirect Investment	
Engineering design and supervision	10,231,000
Architect and engineering contractor	2,436,000
Construction expense	14,494,000
Contractor fees	4,093,000
Total indirect investment	31,254,000
Contingency	28,725,000
Total fixed investment	181,776,000
Other Capital Charges	
Allowance for startup and modifications	18,177,000
Interest during construction	25,449,000
Total depreciable investment	225,402,000
Land	8,262,000
Working capital	13,698,000
Total capital investment	247,362,000
Dollars of total capital per kW of generating capacity	123.68

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.

Landfill site for refuse disposal located 1 mile from coal preparation plant.

NSPS emission level - 1.2 lb SO_2/MBtu. For this 5% sulfur coal, this is also the emission level allowed for the proposed 85% removal NSPS which has a 1.2 lb SO_2/MBtu upper limit.

TABLE B-62. PCC I PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

5% S - 1.2 lb SO_2/MBtu

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	478,100 tons	31.58/ton	15,098,000
Limestone	588,500 tons	7.75/ton	4,561,000
Total raw materials cost			19,659,000
Conversion costs			
Operating labor and supervision	185,100 man-hr	13.80/man-hr	2,554,000
Utilities			
Process water	987,000 kgal	0.11/kgal	109,000
Electricity	158,810,000 kWh	0.039/kWh	6,193,000
Diesel fuel	145,000 gal	0.70/gal	102,000
Steam	1,902,000 klb	2.35/klb	4,470,000
Process material: magnetite, Grade E	2,760 tons	93.31/ton	257,000
Maintenance			7,308,000
Analyses	10,100 man-hr	18.70/man-hr	189,000
Total conversion costs			21,182,000
Total direct costs			40,841,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			13,524,000
Average cost of capital and taxes			21,273,000
Overheads			
Plant			4,087,000
Administrative			256,000
Marketing			-
Total indirect costs			39,140,000
Gross annual revenue requirements			79,981,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			79,981,000

	Mills/kWh	¢/lb S removed
Equivalent unit revenue requirements	7.27	18.99

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 yr; operating time, 6,000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $121,797,000; total depreciable investment, $225,402,000; and total capital investment, $247,362,000.

Raw coal (moisture-free): 4,840,000 tons/yr, 5% S, 16.7% ash, 12,000 Btu/lb, and 4.17 lb S/MBtu.

Clean coal (moisture-free): 4,073,000 tons/yr, 3.67% S, 10.09% ash, 13,000 Btu/lb, and 2.84 lb S/MBtu.

NSPS emission level - 1.2 lb SO_2/MBtu. For this 5% S coal, this is also the emission level allowed for the proposed 85% removal NSPS which has a 1.2 lb SO_2/MBtu upper limit.

TABLE B-63. PCC I PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

0.7% S - 85% removal

	Investment, $
Direct Investment	
Raw material handling and preparation	12,147,000
Raw coal sizing	1,616,000
Coarse coal cleaning	1,575,000
Intermediate coal cleaning	2,234,000
Fine coal cleaning	2,696,000
Clean coal storage	8,459,000
Scrubbing	52,063,000
Waste disposal	9,950,000
Total areas	90,740,000
Services, utilities, and miscellaneous	5,444,000
Total direct investment	96,184,000
Indirect Investment	
Engineering design and supervision	8,079,000
Architect and engineering contractor	1,923,000
Construction expense	11,446,000
Contractor fees	3,232,000
Total indirect investment	24,680,000
Contingency	22,356,000
Total fixed investment	143,220,000
Other Capital Charges	
Allowance for startup and modifications	14,322,000
Interest during construction	20,051,000
Total depreciable investment	177,593,000
Land	3,316,000
Working capital	13,346,000
Total capital investment	194,255,000
Dollars of total capital per kW of generating capacity	97.13

Basis
- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.
- Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.
- Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-64. PCC I PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

0.7% S - 85% removal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	283,400 tons	31.58/ton	8,949,000
Limestone	98,400 tons	7.75/ton	763,000
Total raw materials cost			9,712,000
Conversion costs			
Operating labor and supervision	172,100 man-hr	13.80/man-hr	2,375,000
Utilities			
Process water	646,000 kgal	0.11/kgal	71,000
Electricity	151,870,000 kWh	0.039/kWh	5,923,000
Diesel fuel	97,000 gal	0.70/gal	68,000
Steam	1,803,000 klb	2.35/klb	4,237,000
Process material: magnetite, Grade E	2,720 tons	93.31/ton	254,000
Maintenance			5,771,000
Analyses	8,200 man-hr	18.70/man-hr	153,000
Total conversion costs			18,852,000
Total direct costs			28,564,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			10,656,000
Average cost of capital and taxes			16,706,000
Overheads			
Plant			3,244,000
Administrative			238,000
Marketing			-
Total indirect costs			30,844,000
Gross annual revenue requirements			59,408,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			59,408,000

	Mills/kWh	¢/lb S removed
Equivalent unit revenue requirements	5.40	105

Basis
- Midwest coal-cleaning plant location; time basis for [illegible]g, mid-1982; plant life, 30 yr; operating time, 6,000 hr/yr.
- Clean coal production capacity for 2,000 MW, co[illegible]ower plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $96,184,000; total de[illegible]ble investment, $177,593,000, and total capital investment, $194,255,000.
- Raw coal (moisture-free): 4,777,000 tons/yr, 0.7% S, 11.5% ash, 11,700 Btu/lb, and 0.60 lb S/MBtu.
- Clean coal (moisture-free): 4,354,000 tons/yr, 0.62% S, 7.88% ash, 12,200 Btu/lb, and 0.51 lb S/MBtu.
- NSPS emission level - 0.20 lb SO_2/MBtu.

TABLE B-65. PCC I PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

2% S - 85% removal	Investment, $
Direct Investment	
Raw material handling and preparation	14,439,000
Raw coal sizing	1,543,000
Coarse coal cleaning	1,512,000
Intermediate coal cleaning	2,132,000
Fine coal cleaning	2,573,000
Clean coal storage	8,028,000
Scrubbing	47,083,000
Waste disposal	14,204,000
Total areas	91,514,000
Services, utilities, and miscellaneous	5,491,000
Total direct investment	97,005,000
Indirect Investment	
Engineering design and supervision	8,148,000
Architect and engineering contractor	1,940,000
Construction expense	11,544,000
Contractor fees	3,259,000
Total indirect investment	24,891,000
Contingency	22,590,000
Total fixed investment	144,486,000
Other Capital Charges	
Allowance for startup and modifications	14,449,000
Interest during construction	20,228,000
Total depreciable investment	179,163,000
Land	4,813,000
Working capital	11,571,000
Total capital investment	195,547,000
Dollars of total capital per kW of generating capacity	97.77

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.

Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-66. PCC I PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

2% S - 85% removal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	315,600 tons	31.58/ton	9,966,000
Limestone	172,200 tons	7.75/ton	1,335,000
Total raw materials cost			11,301,000
Conversion costs			
Operating labor and supervision	177,000 man-hr	13.80/man-hr	2,443,000
Utilities			
Process water	670,000 kgal	0.11/kgal	74,000
Electricity	140,990,000 kWh	0.039/kWh	5,498,000
Diesel fuel	119,000 gal	0.70/gal	83,000
Steam	1,819,000 klb	2.35/klb	4,275,000
Process material: magnetite, Grade E	2,490 tons	93.31/ton	232,000
Maintenance			5,820,000
Analyses	8,900 man-hr	18.70/man-hr	166,000
Total conversion costs			18,591,000
Total direct costs			29,892,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			10,750,000
Average cost of capital and taxes			16,817,000
Overheads			
Plant			3,321,000
Administrative			245,000
Marketing			-
Total indirect costs			31,133,000
Gross annual revenue requirements			61,025,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			61,025,000

	Mills/kWh	¢/lb S removed
Equivalent unit revenue requirements	5.55	41.1

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 yr; operating time, 6,000 hr/yr.
- Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $97,005,000; total depreciable investment, $179,163,000; and total capital investment, $195,547,000.
- Raw coal (moisture-free): 4,362,000 tons/yr, 2% S, 14.5% ash, 12,800 Btu/lb, and 1.56 lb S/MBtu.
- Clean coal (moisture-free): 3,749,000 tons/yr, 1.36% S, 7.45% ash, 14,000 Btu/lb, and 0.97 lb S/MBtu.
- NSPS emission level - 0.47 lb SO_2/MBtu.

TABLE B-67. PCC I PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

3.5% S - 85% removal

	Investment, $
Direct Investment	
Raw material handling and preparation	15,667,000
Raw coal sizing	1,564,000
Coarse coal cleaning	1,547,000
Intermediate coal cleaning	2,162,000
Fine coal cleaning	2,594,000
Clean coal storage	8,048,000
Scrubbing	48,678,000
Waste disposal	21,668,000
Total areas	101,928,000
Services, utilities, and miscellaneous	6,115,000
Total direct investment	108,043,000
Indirect Investment	
Engineering design and supervision	9,075,000
Architect and engineering contractor	2,161,000
Construction expense	12,857,000
Contractor fees	3,630,000
Total indirect investment	27,723,000
Contingency	25,348,000
Total fixed investment	161,114,000
Other Capital Charges	
Allowance for startup and modifications	16,111,000
Interest during construction	22,556,000
Total depreciable investment	199,781,000
Land	6,187,000
Working capital	12,321,000
Total capital investment	218,289,000
Dollars of total capital per kW of generating capacity	109.14

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.

Landfill site for refuse disposal located 1 mile from coal preparation plant.

TABLE B-68. PCC I PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

3.5% S - 85% removal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	368,650 tons	31.58/ton	11,642,000
Limestone	355,700 tons	7.75/ton	2,757,000
Total raw materials cost			14,399,000
Conversion costs			
Operating labor and supervision	181,700 man-hr	13.80/man-hr	2,508,000
Utilities			
Process water	812,000 kgal	0.11/kgal	89,000
Electricity	147,960,000 kWh	0.039/kWh	5,770,000
Diesel fuel	121,000 gal	0.70/gal	85,000
Steam	1,871,000 klb	2.35/klb	4,397,000
Process material: magnetite, Grade E	2,550 tons	93.31/ton	238,000
Maintenance			6,482,000
Analyses	9,600 man-hr	18.70/man-hr	180,000
Total conversion costs			19,749,000
Total direct costs			34,148,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			11,987,000
Average cost of capital and taxes			18,773,000
Overheads			
Plant			3,685,000
Administrative			251,000
Marketing			-
Total indirect costs			34,696,000
Gross annual revenue requirements			68,844,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			68,844,000

	Mills/kWh	¢/lb S removed
Equivalent unit revenue requirements	6.26	25.83

Basis
Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 yr; operating time, 6,000 hr/yr.
Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
Total direct investment, $108,043,000; total depreciable investment, $199,781,000; and total capital investment, $218,289,000.
Raw coal (moisture-free): 4,480,000 tons/yr, 3.5% S, 14.0% ash, 12,500 Btu/lb, and 2.79 lb S/MBtu.
Clean coal (moisture-free): 3,862,000 tons/yr, 2.55% S, 7.99% ash, 13,400 Btu/lb, and 1.91 lb S/MBtu.
NSPS emission level - 0.84 lb SO_2/MBtu.

TABLE B-69. PCC I PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

5% S - 85% removal

	Investment, $
Direct Investment	
Raw material handling and preparation	17,612,000
Raw coal sizing	1,627,000
Coarse coal cleaning	1,585,000
Intermediate coal cleaning	2,249,000
Fine coal cleaning	2,696,000
Clean coal storage	8,261,000
Scrubbing	51,033,000
Waste disposal	29,840,000
Total areas	114,903,000
Services, utilities, and miscellaneous	6,894,000
Total direct investment	121,797,000
Indirect Investment	
Engineering design and supervision	10,231,000
Architect and engineering contractor	2,436,000
Construction expense	14,494,000
Contractor fees	4,093,000
Total indirect investment	31,254,000
Contingency	28,725,000
Total fixed investment	181,776,000
Other Capital Charges	
Allowance for startup and modifications	18,177,000
Interest during construction	25,449,000
Total depreciable investment	225,402,000
Land	8,262,000
Working capital	13,698,000
Total capital investment	247,362,000
Dollars of total capital per kW of generating capacity	123.68

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 6,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs (excluding Btu loss), and 7 weeks operating overheads.

Landfill site for refuse disposal located 1 mile from coal preparation plant.

NSPS emission level - 1.2 lb SO_2/MBtu. For this 5% sulfur coal, this is also the emission level allowed for the proposed 85% removal NSPS which has a 1.2 lb SO_2/MBtu upper limit.

TABLE B-70. PCC I PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

5% S - 85% removal

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Coal loss (Btu basis)	478,100 tons	31.58/ton	15,098,000
Limestone	588,500 tons	7.75/ton	4,561,000
Total raw materials cost			19,659,000
Conversion costs			
Operating labor and supervision	185,100 man-hr	13.80/man-hr	2,554,000
Utilities			
Process water	987,000 kgal	0.11/kgal	109,000
Electricity	158,810,000 kWh	0.039/kWh	6,193,000
Diesel fuel	145,000 gal	0.70/gal	102,000
Steam	1,902,000 klb	2.35/klb	4,470,000
Process material: magnetite, Grade E	2,760 tons	93.31/ton	257,000
Maintenance			7,308,000
Analyses	10,100 man-hr	18.70/man-hr	189,000
Total conversion costs			21,182,000
Total direct costs			40,841,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			13,524,000
Average cost of capital and taxes			21,273,000
Overheads			
Plant			4,087,000
Administrative			256,000
Marketing			-
Total indirect costs			39,140,000
Gross annual revenue requirements			79,981,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			79,981,000

	Mills/kWh	¢/lb S removed
Equivalent unit revenue requirements	7.27	18.99

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 yr; operating time, 6,000 hr/yr.
- Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $121,797,000; total depreciable investment, $225,402,000; and total capital investment, $247,362,000.
- Raw coal (moisture-free): 4,840,000 tons/yr, 5% S, 16.7% ash, 12,000 Btu/lb, and 4.17 lb S/MBtu.
- Clean coal (moisture-free): 4,073,000 tons/yr, 3.67% S, 10.09% ash, 13,000 Btu/lb, and 2.84 lb S/MBtu.
- NSPS emission level - 1.2 lb SO_2/MBtu. For this 5% S coal, this is also the emission level allowed for the proposed 85% removal NSPS which has a 1.2 lb SO_2/MBtu upper limit.

TABLE B-71. KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

3.5% S - 1.2 lb SO_2/MBtu NSPS

	Investment, $
Direct Investment	
Raw material handling and preparation	11,819,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Scrubbing	16,583,000
Waste disposal	16,194,000
Subtotal	92,764,000
Services, utilities, and miscellaneous	5,155,000
Total direct investment	97,919,000
Indirect Investment	
Engineering design and supervision	8,595,000
Architect and engineering contractor	1,579,000
Construction expense	12,430,000
Contractor fees	3,692,000
Total indirect investment	26,296,000
Contingency	24,843,000
Total fixed investment	149,058,000
Other Capital Charges	
Allowance for startup and modifications	14,906,000
Interest during construction	20,868,000
Total depreciable investment	184,832,000
Land	3,352,000
Working capital	19,356,000
Total capital investment	207,540,000
Dollars of total capital per kW of generating capacity	103.8

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-72. KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

3.5% S - 1.2 lb SO_2/MBtu NSPS

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	31,303 tons	7.75/ton	243,000
Lime	137,952 tons	43.31/ton	5,975,000
Oxygen	198,784 tons	21.13/ton	4,200,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	128,576 tons	99.57/ton	12,802,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 kft^3	2.93/kft^3	70,000
Total raw materials cost			30,177,000
Conversion costs			
Operating labor and supervision	165,878 man-hr	13.80/man-hr	2,289,000
Utilities			
Steam	5,350,723 MBtu	2.54/MBtu	13,591,000
Process water	2,807,020 kgal	0.09/kgal	253,000
Electricity	253,335,413 kWh	0.039/kWh	9,880,000
Maintenance			5,998,000
Analyses	27,274 man-hr	18.70/man-hr	510,000
Total conversion costs			32,521,000
Total direct costs			62,698,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			11,090,000
Average cost of capital and taxes			17,848,000
Overheads			
Plant			1,899,000
Administrative			229,000
Marketing			-
Total indirect costs			31,066,000
Gross annual revenue requirements			93,764,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			93,764,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirement	8.5	55.4

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, KVB - 8,000 hr/yr; FGD - 5,500 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $97,919,000; total depreciable investment, $184,932,000; and total capital investment, $207,640,000.

Raw coal (moisture-free): 4,211,525 tons/yr, 3.5% sulfur, 14.0% ash, 12,700 Btu/lb, and 2.8 lb S/MBtu.

Clean coal (moisture-free): 3,988,549 tons/yr, 0.98% sulfur, 10.3% ash, 13,100 Btu/lb, and 0.8 lb S/MBtu.

NSPS emission level - 1.2 lb SO_2/MBtu.

TABLE B-73. KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

5% S - 1.2 lb SO_2/MBtu NSPS

	Investment, $
Direct Investment	
Raw material handling and preparation	13,852,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Scrubbing	31,628,000
Waste disposal	23,396,000
Subtotal	117,044,000
Services, utilities, and miscellaneous	5,749,000
Total direct investment	122,793,000
Indirect Investment	
Engineering design and supervision	10,466,000
Architect and engineering contractor	1,586,000
Construction expense	16,210,000
Contractor fees	4,785,000
Total indirect investment	33,047,000
Contingency	30,920,000
Total fixed investment	186,760,000
Other Capital Charges	
Allowance for startup and modifications	18,676,000
Interest during construction	26,146,000
Total depreciable investment	231,582,000
Land	4,726,000
Working capital	21,685,000
Total capital investment	257,993,000
Dollars of total capital per kW of generating capacity	129.0

Basis
- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.
- Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.
- Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-74. KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

5% S - 1.2 lb SO_2/MBtu NSPS

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	90,004 tons	7.75/ton	698,000
Lime	197,603 tons	43.31/ton	8,558,000
Oxygen	297,600 tons	21.13/ton	6,288,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	152,880 tons	99.57/ton	15,222,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 kft^3	2.93/kft^3	70,000
Total raw materials cost			37,723,000
Conversion costs			
Operating labor and supervision	174,694 man-hr	13.80/man-hr	2,411,000
Utilities			
Steam	5,349,838 MBtu	2.54/MBtu	13,589,000
Process water	3,005,871 kgal	0.09/kgal	271,000
Electricity	293,591,132 kWh	0.039/kWh	11,450,000
Maintenance			7,460,000
Analyses	27,338 man-hr	18.70/man-hr	511,000
Total conversion costs			35,692,000
Total direct costs			73,415,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			13,895,000
Average cost of capital and taxes			22,187,000
Overheads			
Plant			2,595,000
Administrative			241,000
Marketing			-
Total indirect costs			38,918,000
Gross annual revenue requirements			112,333,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			112,333,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirement	10.2	29.9

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, KVB - 8,000 hr/yr; FGD - 5,500 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $122,793,000; total depreciable investment, $231,284,000; and total capital investment, $257,695,000.

Raw coal (moisture-free): 4,378,650 tons/yr, 5.0% sulfur, 16.7% ash, 12,000 Btu/lb, and 4.2 lb S/MBtu.

Clean coal (moisture-free): 4,146,825 tons/yr, 1.3% sulfur, 11.4% ash, 12,600 Btu/lb, and 1.0 lb S/MBtu.

NSPS emission level - 1.2 lb SO_2/MBtu. For this 5% sulfur coal, this is also the emission level allowed for the proposed 85% removal NSPS which has a 1.2 lb SO_2/MBtu upper limit.

TABLE B-75. KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

0.7% S - 85% Removal NSPS	Investment, $
Direct Investment	
Raw material handling and preparation	13,223,000
Sulfur oxidation	6,292,000
Reactor off-gas cleaning	11,448,000
Fine coal leaching	7,906,000
Coarse coal leaching	7,141,000
Product agglomeration and handling	12,212,000
Leach solution neutralization and water handling	6,250,000
Scrubbing	33,507,000
Waste disposal	8,797,000
Subtotal	106,776,000
Services, utilities, and miscellaneous	5,755,000
Total direct investment	112,531,000
Indirect Investment	
Engineering design and supervision	10,226,000
Architect and engineering contractor	1,568,000
Construction expense	15,317,000
Contractor fees	4,553,000
Total indirect investment	31,664,000
Contingency	28,838,000
Total fixed investment	173,033,000
Other Capital Charges	
Allowance for startup and modifications	17,303,000
Interest during construction	24,225,000
Total depreciable investment	214,561,000
Land	1,760,000
Working capital	17,747,000
Total capital investment	234,068,000
Dollars of total capital per kW of generating capacity	117.0

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-76. KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

0.7% S - 85% Removal NSPS

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	39,600 tons	7.75/ton	307,000
Lime	22,200 tons	43.31/ton	962,000
Oxygen	25,216 tons	21.13/ton	533,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	35,424 tons	99.57/ton	3,527,000
Sodium lignin sulfonate	81,200 tons	83.17/ton	6,753,000
Natural gas	24,000 kft^3	2.93/kft^3	70,000
Total raw materials cost			12,785,000
Conversion costs			
Operating labor and supervision	176,948 man-hr	13.80/man-hr	2,442,000
Utilities			
Steam	6,958,287 MBtu	2.54/MBtu	17,674,000
Process water	3,303,406 kgal	0.09/kgal	297,000
Electricity	336,478,753 kWh	0.039/kWh	13,123,000
Maintenance			7,596,000
Analyses	27,672 man-hr	18.70/man-hr	517,000
Total conversion costs			41,649,000
Total direct costs			54,760,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			12,874,000
Average cost of capital and taxes			20,129,000
Overheads			
Plant			2,956,000
Administrative			244,000
Marketing			-
Total indirect costs			36,203,000
Gross annual revenue requirements			90,963,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			90,963,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirement	8.3	197.8

Basis
Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, KVB - 8,000 hr/yr; FGD - 5,500 hr/yr.
Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
Total direct investment, $112,531,000; total depreciable investment, $214,561,000; and total capital investment, $234,068,000.
Raw coal (moisture-free): 4,715,468 tons/yr, 0.7% sulfur, 11.5% ash, 11,700 Btu/lb, and 0.6 lb S/MBtu.
Clean coal (moisture-free): 4,465,812 tons/yr, 0.36% sulfur, 11.2% ash, 11,700 Btu/lb, and 0.3 lb S/MBtu.
NSPS emmission level - 0.20 lb SO_2/MBtu.

TABLE B-77. KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

2.0% S - 85% Removal NSPS

	Investment, $
Direct Investment	
Raw material handling and preparation	12,119,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Scrubbing	25,471,000
Waste disposal	12,542,000
Subtotal	98,300,000
Services, utilities, and miscellaneous	5,361,000
Total direct investment	103,661,000
Indirect Investment	
Engineering design and supervision	9,431,000
Architect and engineering contractor	1,569,000
Construction expense	13,753,000
Contractor fees	4,091,000
Total indirect investment	28,844,000
Contingency	26,501,000
Total fixed investment	159,006,000
Other Capital Charges	
Allowance for startup and modifications	15,901,000
Interest during construction	22,261,000
Total depreciable investment	197,168,000
Land	2,572,000
Working capital	18,220,000
Total capital investment	217,960,000
Dollars of total capital per kW of generating capacity	109.0

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-78. KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

2% S - 85% Removal NSPS

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	36,883 tons	7.75/ton	286,000
Lime	89,416 tons	43.31/ton	3,873,000
Oxygen	117,232 tons	21.13/ton	2,477,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	70,224 tons	99.57/ton	6,992,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 kft^3	2.93/kft^3	70,000
Total raw materials cost			20,585,000
Conversion costs			
Operating labor and supervision	171,577 man-hr	13.80/man-hr	2,368,000
Utilities			
Steam	5,352,009 MBtu	2.54/MBtu	13,594,000
Process water	2,965,076 kgal	0.09/kgal	267,000
Electricity	290,438,594 kWh	0.039/kWh	11,327,000
Maintenance			6,726,000
Analyses	26,884 man-hr	18.70/man-hr	503,000
Total conversion costs			34,785,000
Total direct costs			55,370,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			11,830,000
Average cost of capital and taxes			18,745,000
Overheads			
Plant			2,453,000
Administrative			237,000
Marketing			-
Total indirect costs			33,265,000
Gross annual revenue requirements			88,635,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			88,635,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirement	8.1	42.6

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, KVB - 8,000 hr/yr; FGD - 5,500 hr/yr.
- Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $103,661,000; total depreciable investment, $197,168,000; and total capital investment, $217,960,000.
- Raw coal (moisture-free): 4,117,238 tons/yr, 2.0% sulfur, 14.5% ash, 13,000 Btu/lb, and 1.5 lb S/MBtu.
- Clean coal (moisture-free): 3,899,254 tons/yr, 0.53% sulfur, 11.6% ash, 13,400 Btu/lb, and 0.4 lb S/MBtu.
- NSPS emission level - 0.45 lb SO_2/MBtu.

TABLE B-79. KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

3.5% S - 85% Removal NSPS

	Investment, $
Direct Investment	
Raw material handling and preparation	12,361,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Scrubbing	21,850,000
Waste disposal	19,049,000
Subtotal	101,429,000
Services, utilities, and miscellaneous	6,086,000
Total direct investment	107,515,000
Indirect Investment	
Engineering design and supervision	10,969,000
Architect and engineering contractor	1,701,000
Construction expense	16,431,000
Contractor fees	4,926,000
Total indirect investment	34,027,000
Contingency	28,308,000
Total fixed investment	169,850,000
Other Capital Charges	
Allowance for startup and modifications	16,985,000
Interest during construction	23,779,000
Total depreciable investment	210,614,000
Land	3,828,000
Working capital	20,223,000
Total capital investment	234,665,000
Dollars of total capital per kW of generating capacity	117.3

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-80. KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

3.5% S - 85% Removal NSPS

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	70,888 tons	7.75/ton	549,000
Lime	137,952 tons	43.31/ton	5,975,000
Oxygen	198,784 tons	21.13/ton	4,200,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	128,576 tons	99.57/ton	12,802,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 kft^3	2.93/kft^3	70,000
Total raw materials cost			30,483,000
Conversion costs			
Operating labor and supervision	174,227 man-hr	13.80/man-hr	2,404,000
Utilities			
Steam	5,350,723 MBtu	2.54/MBtu	13,591,000
Process water	2,988,275 kgal	0.09/kgal	269,000
Electricity	290,819,931 kWh	0.039/kWh	11,342,000
Maintenance			6,451,000
Analyses	27,274 man-hr	18.70/man-hr	510,000
Total conversion costs			34,567,000
Total direct costs			65,050,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			12,637,000
Average cost of capital and taxes			20,181,000
Overheads			
Plant			2,509,000
Administrative			241,000
Marketing			-
Total indirect costs			35,568,000
Gross annual revenue requirements			100,618,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			100,618,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirement	9.1	40.1

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, KVB - 8,000 hr/yr; FGD - 5,500 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $107,515,000; total depreciable investment, $210,614,000; and total capital investment, $234,665,000.

Raw coal (moisture-free): 4,211,525 tons/yr, 3.5% sulfur, 14.0% ash, 12,700 Btu/lb, and 2.8 lb S/MBtu.

Clean coal (moisture-free): 3,988,549 tons/yr, 0.98% sulfur, 10.3% ash, 13,100 Btu/lb, and 0.8 lb S/MBtu.

NSPS emission level - 0.84 lb SO_2/MBtu.

TABLE B-81. KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

5% S - 85% removal NSPS

	Investment, $
Direct Investment	
Raw material handling and preparation	13,852,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Scrubbing	31,628,000
Waste disposal	23,396,000
Subtotal	117,044,000
Services, utilities, and miscellaneous	5,749,000
Total direct investment	122,793,000
Indirect Investment	
Engineering design and supervision	10,466,000
Architect and engineering contractor	1,586,000
Construction expense	16,210,000
Contractor fees	4,785,000
Total indirect investment	33,047,000
Contingency	30,920,000
Total fixed investment	186,760,000
Other Capital Charges	
Allowance for startup and modifications	18,676,000
Interest during construction	26,146,000
Total depreciable investment	231,582,000
Land	4,726,000
Working capital	21,685,000
Total capital investment	257,993,000
Dollars of total capital per kW of generating capacity	129.0

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides for 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond site for sludge disposal located 1 mile from coal preparation plant.

TABLE B-82. KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

5% S - 85% removal NSPS

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	90,004 tons	7.75/ton	698,000
Lime	197,603 tons	43.31/ton	8,558,000
Oxygen	297,600 tons	21.13/ton	6,288,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	152,880 tons	99.57/ton	15,222,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 kft^3	2.93/kft^3	70,000
Total raw materials cost			37,723,000
Conversion costs			
Operating labor and supervision	174,694 man-hr	13.80/man-hr	2,411,000
Utilities			
Steam	5,349,838 MBtu	2.54/MBtu	13,589,000
Process water	3,005,871 kgal	0.09/kgal	271,000
Electricity	293,591,132 kWh	0.039/kWh	11,450,000
Maintenance			7,460,000
Analyses	27,338 man-hr	18.70/man-hr	511,000
Total conversion costs			35,692,000
Total direct costs			73,415,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			13,895,000
Average cost of capital and taxes			22,187,000
Overheads			
Plant			2,595,000
Administrative			241,000
Marketing			-
Total indirect costs			38,918,000
Gross annual revenue requirements			112,333,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			112,333,000

	Mills/kWh	¢/lb sulfur removed
Equivalent unit revenue requirement	10.2	29.9

Basis
Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 years; operating time, KVB - 8,000 hr/yr; FGD - 5,500 hr/yr.
Clean coal production capacity for 2,000-MW coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
Total direct investment, $122,793,000; total depreciable investment, $231,284,000; and total capital investment, $257,695,000.
Raw coal (moisture-free): 4,378,650 tons/yr, 5.0% sulfur, 16.7% ash, 12,000 Btu/lb, and 4.2 lb S/MBtu.
Clean coal (moisture-free): 4,146,825 tons/yr, 1.3% sulfur, 11.4% ash, 12,600 Btu/lb, and 1.0 lb S/MBtu.
NSPS emission level - 1.2 lb SO_2/MBtu. For this 5% sulfur coal, this is also the emission level allowed for the proposed 85% removal NSPS which has a 1.2 lb SO_2/MBtu upper limit.

TABLE B-83. COMBINATION PCC-KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

3.5% S - 1.2 lb SO_2/MBtu NSPS

	Investment, $
Direct Investment	
Coal receiving and storage	8,608,000
Raw coal sizing	1,564,000
Coarse coal cleaning	1,547,000
Intermediate coal cleaning	2,162,000
Fine coal cleaning	2,594,000
Refuse disposal as landfill	2,581,000
Interim storage area	4,513,000
Raw material handling and preparation	6,737,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Scrubbing	11,219,000
Waste disposal	14,909,000
Subtotal	104,599,000
Services, utilities, and miscellaneous	6,470,000
Total direct investment	111,069,000
Indirect Investment	
Engineering design and supervision	10,330,000
Architect and engineering contractor	2,154,000
Construction expense	14,644,000
Contractor fees	4,280,000
Total indirect investment	31,408,000
Contingency	28,300,000
Total fixed investment	170,777,000
Other Capital Charges	
Allowance for startup and modifications	17,078,000
Interest during construction	23,909,000
Total depreciable investment	211,761,000
Land	6,209,000
Working capital	28,186,000
Total capital investment	246,156,000
Dollars of total capital per kW equivalent of clean coal	123.1

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000 MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond and landfill sites for sludge and refuse disposal located 1 mile from coal preparation plant.

TABLE B-84. COMBINATION PCC-KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

3.5% S - 1.2 lb SO_2/MBtu NSPS

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	17,894 tons	7.75/ton	139,000
Lime	137,952 tons	43.31/ton	5,975,000
Oxygen	198,784 tons	21.13/ton	4,200,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	128,576 tons	99.57/ton	12,802,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 tons	2.93/kft^3	70,000
Coal loss (Btu basis)	368,650 tons	31.58/ton	11,642,000
Total raw materials cost			41,715,000
Conversion costs			
Operating labor and supervision	304,350 man-hr	13.80/man-hr	4,200,000
Utilities			
Diesel fuel	121,000 gal	0.70/gal	85,000
Steam	5,350,723 MBtu	2.54/MBtu	13,591,000
Process water	2,790,058 kgal	0.09/kgal	251,000
Electricity	255,823,565 kWh	0.039/kWh	9,977,000
Process material: magnetite	2,550 tons	93.31/ton	238,000
Maintenance			15,203,000
Analyses	29,072 man-hr	18.70/man-hr	544,000
Total conversion costs			44,089,000
Total direct costs			85,804,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			12,706,000
Average cost of capital taxes			21,169,000
Overheads			
Plant			2,557,000
Administrative			421,000
Marketing			-
Total indirect costs			36,853,000
Gross annual revenue requirements			122,657,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			122,657,000

	Mills/kWh	¢/lb S removed
Equivalent unit revenue requirements	11.2	47.4

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 yr; operating time, PCC-6,000 hr/yr, KVB-8,000 hr/yr, FGD-5,500 hr/yr.
- Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh, and 5,500 hr/yr.
- Total direct investment, $111,069,000 total depreciable investment, $213,695,000, and total capital investment, $248,090,000.
- Raw coal (moisture-free): 4,589,372 tons/yr, 3.5% sulfur, 14.0% ash, 12,700 Btu/lb, and 2.75 lb S/MBtu.
- Clean coal (moisture-free): 3,786,232 tons/yr, 0.98% sulfur, 5.9% ash, 13,800 Btu/lb, and 0.7 lb S/MBtu.
- NSPS emission level: 1.2 lb SO_2/MBtu.

TABLE B-85. COMBINATION PCC-KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

5% S - 1.2 lb SO_2/MBtu NSPS

	Investment, $
Direct Investment	
Coal receiving and storage	8,841,000
Raw coal sizing	1,627,000
Coarse coal cleaning	1,585,000
Intermediate coal cleaning	2,249,000
Fine coal cleaning	2,696,000
Refuse disposal as landfill	3,058,000
Interim storage area	4,513,000
Raw material handling and preparation	8,250,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Scrubbing	25,683,000
Waste disposal	22,060,000
Subtotal	128,730,000
Services, utilities, and miscellaneous	7,541,000
Total direct investment	136,271,000
Indirect Investment	
Engineering design and supervision	12,354,000
Architect and engineering contractor	2,186,000
Construction expense	18,656,000
Contractor fees	5,442,000
Total indirect investment	38,638,000
Contingency	34,748,000
Total fixed investment	209,657,000
Other Capital Charges	
Allowance for startup and modifications	20,966,000
Interest during construction	29,352,000
Total depreciable investment	259,975,000
Land	8,135,000
Working capital	30,085,000
Total capital investment	298,195,000
Dollars of total capital per kW equivalent of clean coal	149.1

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond and landfill sites for sludge and refuse disposal located 1 mile from coal preparation plant.

TABLE B-86. COMBINATION PCC-KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

5% S - 1.2 lb SO_2/MBtu NSPS

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	57,291 tons	7.75/ton	444,000
Lime	197,603 tons	43.31/ton	8,558,000
Oxygen	297,600 tons	21.13/ton	6,288,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	152,880 tons	99.57/ton	15,222,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 tons	2.93/kft^3	70,000
Coal loss (Btu basis)	478,000 tons	31.58/ton	15,098,000
Total raw materials cost			52,567,000
Conversion costs			
Operating labor and supervision	317,872 man-hr	13.80/man-hr	4,387,000
Utilities			
Diesel fuel	145,000 gal	0.70/gal	102,000
Steam	5,349,838 MBtu	2.54/MBtu	13,588,000
Process water	2,940,474 kgal	0.09/kgal	265,000
Electricity	286,664,699 kWh	0.039/kWh	11,180,000
Process material: magnetite	2,760 tons	93.31/ton	257,000
Maintenance			8,862,000
Analyses	30,806 man-hr	18.70/man-hr	576,000
Total conversion costs			39,217,000
Total direct costs			91,784,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			15,599,000
Average cost of capital and taxes			25,645,000
Overheads			
Plant			3,377,000
Administrative			439,000
Marketing			-
Total indirect costs			45,060,000
Gross annual revenue requirements			136,844,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			136,844,000

	Mills/kWh	¢/lb S removed
Equivalent unit revenue requirements	12.4	15.1

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 yr; operating time, PCC-6000 hr/yr, KVB-8,000 hr/yr, FGD-5,500 hr/yr.
- Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $136,271,000; total depreciable investment, $261,956,000; and total capital investment, $300,176,000.
- Raw coal (moisture-free): 4,531,224 tons/yr, 5% sulfur, 16.7% ash, 12,000 Btu/lb, and 4.17 lb S/MBtu.
- Clean coal (moisture-free): 3,928,571 tons/yr, 1.2% sulfur, 6.9% ash, 13,300 Btu/lb, and 0.9 lb S/MBtu.
- NSPS emission level: 1.2 lb SO_2/MBtu. For this 5% coal, this is also the emission level allowed for the proposed 85% removal NSPS which has a 1.2 lb SO_2/MBtu upper limit.

TABLE B-87. COMBINATION PCC-KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

0.7% S - 85% removal NSPS	Investment, $
Direct Investment	
Coal receiving and storage	8,799,000
Raw coal sizing	1,616,000
Coarse coal cleaning	1,575,000
Intermediate coal cleaning	2,234,000
Fine coal cleaning	2,696,000
Refuse disposal as landfill	1,904,000
Interim storage area	4,513,000
Raw material handling and preparation	8,753,000
Sulfur oxidation	6,292,000
Reactor off-gas cleaning	11,448,000
Fine coal leaching	7,906,000
Coarse coal leaching	7,142,000
Product agglomeration and handling	12,212,000
Leach solution neutralization and water handling	6,250,000
Scrubbing	41,054,000
Waste disposal	8,636,000
Subtotal	133,030,000
Services, utilities, and miscellaneous	7,431,000
Total direct investment	140,461,000
Indirect Investment	
Engineering design and supervision	13,327,000
Architect and engineering contractor	2,146,000
Construction expense	19,954,000
Contractor fees	5,898,000
Total indirect investment	41,325,000
Contingency	36,232,000
Total fixed investment	218,018,000
Other Capital Charges	
Allowance for startup and modifications	21,802,000
Interest during construction	30,523,000
Total depreciable investment	270,343,000
Land	3,908,000
Working capital	21,090,000
Total capital investment	295,341,000
Dollars of total capital per kW equivalent of clean coal	147.7

Basis

- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.
- Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.
- Pond and landfill sites for sludge and refuse disposal located 1 mile from coal preparation plant.

TABLE B-88. COMBINATION PCC-KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

0.7% S - 85% removal NSPS

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	36,995 tons	7.75/ton	287,000
Lime	22,200 tons	43.31/ton	962,000
Oxygen	25,216 tons	21.13/ton	533,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	35,424 tons	99.57/ton	3,527,000
Sodium lignin sulfonate	81,200 tons	83.17/ton	6,753,000
Natural gas	24,000 tons	2.93/kft^3	71,000
Coal loss (Btu basis)	283,400 tons	31.58/ton	8,949,000
Total raw materials cost			21,715,000
Conversion costs			
Operating labor and supervision	321,309 man-hr	13.80/man-hr	4,435,000
Utilities			
Diesel fuel	97,000 gal	0.70/gal	68,000
Steam	6,958,287 MBtu	2.54/MBtu	17,674,000
Process water	3,359,753 kgal	0.09/kgal	302,000
Electricity	353,916,849 kWh	0.039/kWh	13,803,000
Process material: magnetite	2,720 tons	93.31/ton	254,000
Maintenance			9,405,000
Analyses	31,724 man-hr	18.70/man-hr	593,000
Total conversion costs			46,534,000
Total direct costs			68,249,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			16,221,000
Average cost of capital and taxes			25,399,000
Overheads			
Plant			3,990,000
Administrative			443,000
Marketing			-
Total indirect costs			46,053,000
Gross annual revenue requirements			114,302,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			114,302,000

	Mills/kWh	¢/lb S removed
Equivalent unit revenue requirements	10.4	174.0

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 yr; operating time, PCC-6,000 hr/yr, KVB-8,000 hr/yr, FGD-5,500 hr/yr.
- Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $140,461,000; total depreciable investment, $251,611,000; and total capital investment, $276,609,000.
- Raw coal (moisture-free): 4,777,448 tons/yr, 0.7% sulfur, 11.5% ash, 11,700 Btu/lb, and 0.6 lb S/MBtu.
- Clean coal (moisture-free): 4,213,709 tons/yr, 0.35% sulfur, 5.8% ash, 12,400 Btu/lb, and 0.28 lb S/MBtu.
- NSPS emission level: 0.20 lb SO_2/MBtu

TABLE B-89. COMBINATION PCC-KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

2% S - 85% reduction NSPS

	Investment, $
Direct Investment	
Coal receiving and storage	8,529,000
Raw coal sizing	1,543,000
Coarse coal cleaning	1,512,000
Intermediate coal cleaning	2,132,000
Fine coal cleaning	2,573,000
Refuse disposal as landfill	2,558,000
Interim storage area	4,513,000
Raw material handling and preparation	8,202,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Scrubbing	25,620,000
Waste disposal	11,737,000
Subtotal	117,087,000
Services, utilities, and miscellaneous	7,011,000
Total direct investment	124,098,000
Indirect Investment	
Engineering design and supervision	11,822,000
Architect and engineering contractor	2,139,000
Construction expense	17,139,000
Contractor fees	5,047,000
Total indirect investment	36,147,000
Contingency	31,864,000
Total fixed investment	192,109,000
Other Capital Charges	
Allowance for startup and modifications	19,211,000
Interest during construction	26,895,000
Total depreciable investment	238,215,000
Land	5,417,000
Working capital	26,673,000
Total capital investment	270,305,000
Dollars of total capital per kW equivalent of clean coal	135.2

Basis
- Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.
- Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).
- Working capital provides 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.
- Pond and landfill sites for sludge and refuse disposal located 1 mile from coal preparation plant.

TABLE B-90. COMBINATION PCC-KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

2% S - 85% reduction NSPS

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	21,858 tons	7.75/ton	169,000
Lime	89,416 tons	43.31/ton	3,873,000
Oxygen	117,232 tons	21.13/ton	2,477,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	70,224 tons	99.57/ton	6,992,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 tons	2.93/kft^3	70,000
Coal loss (Btu basis)	315,600 tons	31.58/ton	9,966,000
Total raw materials cost			30,434,000
Conversion costs			
Operating labor and supervision	314,700 man-hr	13.80/man-hr	4,384,000
Utilities			
Diesel fuel	119,000 gal	0.70/gal	83,000
Steam	5,352,009 MBtu	2.54/MBtu	13,594,000
Process water	2,909,150 kgal	0.09/kgal	262,000
Electricity	284,860,387 kWh	0.039/kWh	11,110,000
Process material: magnetite	2,490 tons	93.31/ton	232,000
Maintenance			8,191,000
Analyses	30,402 man-hr	18.70/man-hr	569,000
Total conversion costs			38,425,000
Total direct costs			68,859,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			14,293,000
Average cost of capital and taxes			23,246,000
Overheads			
Plant			3,314,000
Administrative			134,000
Marketing			-
Total indirect costs			40,987,000
Gross annual revenue requirements			109,846,000
Byproduct Sales Revenue			-
None			
Total annual revenue requirements			109,846,000

	Mills/kWh	¢/lb S removed
Equivalent unit revenue requirements	10.0	72.3

Basis
Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, **30 yr; operating time, PCC-6,000 hr/yr, KVB-8,000 hr/yr, FGD-5,500 hr/yr.**
Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
Total direct investment, $124,098,000; total depreciable investment, $239,736,000; and total capital investment, $271,826,000.
Raw coal (moisture-free): 4,401,408 tons/yr, 2% sulfur, 14.5% ash, 13,000 Btu/lb, and 1.54 lb S/MBtu.
Clean coal (moisture-free): 3,679,577 tons/yr, 0.49% sulfur, 6.0% ash, 14,200 Btu/lb, and 0.35 lb S/MBtu.
NSPS emission level: 0.462 lb SO_2/MBtu

TABLE B-91. COMBINATION PCC-KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

3.5% S - 85% removal NSPS

	Investment, $
Direct Investment	
Coal receiving and storage	8,608,000
Raw coal sizing	1,564,000
Coarse coal cleaning	1,547,000
Intermediate coal cleaning	2,162,000
Fine coal cleaning	2,594,000
Refuse disposal as landfill	2,581,000
Interim storage area	4,513,000
Raw material handling and preparation	7,730,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Scrubbing	29,337,000
Waste disposal	18,545,000
Subtotal	127,349,000
Services, utilities, and miscellaneous	6,024,000
Total direct investment	133,373,000
Indirect Investment	
Engineering design and supervision	12,443,000
Architect and engineering contractor	2,154,000
Construction expense	18,400,000
Contractor fees	5,454,000
Total indirect investment	38,451,000
Contingency	34,404,000
Total fixed investment	206,228,000
Other Capital Charges	
Allowance for startup and modifications	20,623,000
Interest during construction	28,872,000
Total depreciable investment	255,723,000
Land	6,787,000
Working capital	29,267,000
Total capital investment	291,777,000
Dollars of total capital per kW equivalent of clean coal	145.9

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond and landfill sites for sludge and refuse disposal located 1 mile from coal preparation plant.

TABLE B-92. COMBINATION PCC-KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

3.5% S - 85% removal NSPS	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	63,954 tons	7.75/ton	496,000
Lime	137,952 tons	43.31/ton	5,975,000
Oxygen	198,784 tons	21.13/ton	4,200,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	128,576 tons	99.57/ton	12,802,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 tons	$2.93/\text{kft}^3$	70,000
Coal loss (Btu basis)	368,650 tons	31.58/ton	11,642,000
Total raw materials cost			42,072,000
Conversion costs			
Operating labor and supervision	317,193 man-hr	13.80/man-hr	4,377,000
Utilities			
Diesel fuel	121,000 gal	0.70/gal	85,000
Steam	5,350,723 MBtu	2.54/MBtu	13,591,000
Process water	3,015,488 kgal	0.09/kgal	271,000
Electricity	302,893,233 kWh	0.039/kWh	11,813,000
Process material: magnetite	2,550 tons	93.31/ton	238,000
Maintenance			8,702,000
Analyses	31,118 man-hr	18.70/man-hr	582,000
Total conversion costs			39,659,000
Total direct costs			81,731,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			15,343,000
Average cost of capital and taxes			25,093,000
Overheads			
Plant			3,445,000
Administrative			438,000
Marketing			-
Total indirect costs			44,319,000
Gross annual revenue requirements			126,050,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			126,050,000

	Mills/kWh	¢/lb S removed
Equivalent unit revenue requirements	11.5	45.3

Basis
- Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 yr; operating time, PCC-6,000 hr/yr, KVB-8,000 hr/yr, FGD-5,500 hr/yr.
- Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.
- Total direct investment, $133,373,000; total depreciable investment, $255,723,000; and total capital investment, $291,777,000.
- Raw coal (moisture-free): 4,589,372 tons/yr, 3.5% sulfur, 14.0% ash, 12,700 Btu/lb, and 2.75 lb S/MBtu.
- Clean coal (moisture-free): 3,786,232 tons/yr, 0.98% sulfur, 5.9% ash, 13,800 Btu/lb, and 0.7 lb S/MBtu.
- NSPS emission level: 0.826 lb SO_2/MBtu.

TABLE B-93. COMBINATION PCC-KVB PROCESS AND FGD

TOTAL CAPITAL INVESTMENT

5% S - 85% removal NSPS	Investment, $
Direct Investment	
Coal receiving and storage	8,841,000
Raw coal sizing	1,627,000
Coarse coal cleaning	1,585,000
Intermediate coal cleaning	2,249,000
Fine coal cleaning	2,696,000
Refuse disposal as landfill	3,058,000
Interim storage area	4,513,000
Raw material handling and preparation	8,250,000
Sulfur oxidation	5,985,000
Reactor off-gas cleaning	10,889,000
Fine coal leaching	7,427,000
Coarse coal leaching	6,625,000
Product agglomeration and handling	11,329,000
Leach solution neutralization and water handling	5,913,000
Scrubbing	25,683,000
Waste disposal	22,060,000
Subtotal	128,730,000
Services, utilities, and miscellaneous	7,541,000
Total direct investment	136,271,000
Indirect Investment	
Engineering design and supervision	12,354,000
Architect and engineering contractor	2,186,000
Construction expense	18,656,000
Contractor fees	5,442,000
Total indirect investment	38,638,000
Contingency	34,748,000
Total fixed investment	209,657,000
Other Capital Charges	
Allowance for startup and modifications	20,966,000
Interest during construction	29,352,000
Total depreciable investment	259,975,000
Land	8,135,000
Working capital	30,085,000
Total capital investment	298,195,000
Dollars of total capital per kW equivalent of clean coal	149.1

Basis

Midwest location of coal-cleaning plant with project beginning mid-1979, ending mid-1982; average basis for cost scaling, end-1980; operating time, 8,000 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Fifteen-day raw coal and fifteen-day clean coal storage capacities (power plant basis).

Working capital provides 3 weeks raw coal consumption, 7 weeks direct revenue costs, and 7 weeks operating overheads.

Pond and landfill sites for sludge and refuse disposal located 1 mile from coal preparation plant.

TABLE B-94. COMBINATION PCC-KVB PROCESS AND FGD

ANNUAL REVENUE REQUIREMENTS

5% S - 85% removal NSPS

	Annual quantity	Unit cost, $	Total annual cost, $
Direct Costs			
Raw materials			
Limestone	57,291 tons	7.75/ton	444,000
Lime	197,603 tons	43.31/ton	8,558,000
Oxygen	297,600 tons	21.13/ton	6,288,000
NO_2	952 tons	665.28/ton	633,000
NaOH (50%)	152,880 tons	99.57/ton	15,222,000
Sodium lignin sulfonate	75,200 tons	83.17/ton	6,254,000
Natural gas	24,000 tons	2.93/kft^3	70,000
Coal loss (Btu basis)	478,000 tons	31.58/ton	15,098,000
Total raw materials cost			52,567,000
Conversion costs			
Operating labor and supervision	317,872 man-hr	13.80/man-hr	4,387,000
Utilities			
Diesel fuel	145,000 gal	0.70/gal	102,000
Steam	5,349,838 MBtu	2.54/MBtu	13,588,000
Process water	2,940,474 kgal	0.09/kgal	265,000
Electricity	286,664,699 kWh	0.039/kWh	11,180,000
Process material: magnetite	2,760 tons	93.31/ton	257,000
Maintenance			8,862,000
Analyses	30,806 man-hr	18.70/man-hr	576,000
Total conversion costs			39,217,000
Total direct costs			91,784,000
Indirect Costs			
Capital charges			
Depreciation, interim replacements, and insurance			15,599,000
Average cost of capital and taxes			25,645,000
Overheads			
Plant			3,377,000
Administrative			439,000
Marketing			-
Total indirect costs			45,060,000
Gross annual revenue requirements			136,844,000
Byproduct Sales Revenue			
None			-
Total annual revenue requirements			136,844,000

	Mills/kWh	c/lb S removed
Equivalent unit revenue requirements	12.4	35.1

Basis

Midwest coal-cleaning plant location; time basis for scaling, mid-1982; plant life, 30 yr; operating time, PCC-6000 hr/yr, KVB-8,000 hr/yr, FGD-5,500 hr/yr.

Clean coal production capacity for 2,000-MW, coal-fired power plant operating at 9,500 Btu/kWh and 5,500 hr/yr.

Total direct investment, $136,271,000; total depreciable investment, $261,956,000; and total capital investment, $300,176,000.

Raw coal (moisture-free): 4,531,224 tons/yr, 5% sulfur, 16.7% ash, 12,000 Btu/lb, and 4.17 lb S/MBtu.

Clean coal (moisture-free): 3,928,571 tons/yr, 1.2% sulfur, 6.9% ash, 13,300 Btu/lb, and 0.9 lb S/MBtu.

NSPS emission level: 1.2 lb SO_2/MBtu. For this 5% coal, this is also the emission level allowed for the proposed 85% removal NSPS which has a 1.2 lb SO_2/MBtu upper limit.